BIRLA CENTRAL LIBRARY
PILANI (RAJASTHAN)
Class No 621.384
Book No H62P
Accession No. 31693

PRINCIPLES AND PRACTICE
of
RADIO SERVICING

The quality of the materials used in the manufacture of this book is governed by continued postwar shortages.

Principles and Practice *of* Radio Servicing

BY

H. J. HICKS, M.S.
Associate Radio Engineer, Aircraft Radio Laboratory, Wright Field, Dayton; Formerly Radio Instructor, Hadley Technical High School, St. Louis

SECOND EDITION
NINTH IMPRESSION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK AND LONDON
1943

PRINCIPLES AND PRACTICE OF RADIO SERVICING

COPYRIGHT, 1939, 1943, BY THE
McGRAW-HILL BOOK COMPANY, INC.

PRINTED IN THE UNITED STATES OF AMERICA

All rights reserved. This book, or parts thereof, may not be reproduced in any form without permission of the publishers.

THE MAPLE PRESS COMPANY, YORK, PA.

PREFACE TO THE SECOND EDITION

The author wishes to extend his thanks to the many teachers and servicemen for the cordial reception they have given this book. He is especially grateful to those who have expressed their appreciation of the book and for their helpful criticisms and corrections.

This second edition is really a new book. It is true that some parts of the first edition have been retained. However, every paragraph and every figure pertaining to obsolete methods or circuits have been eliminated. Much new material, such as signal tracing, frequency modulation, and modern antennas, has been added and many new diagrams and several original photographs are included.

Again the author wishes to express his appreciation of the most helpful assistance of Mr. Oscar Gotsch in proofreading the manuscript and for his many excellent suggestions.

H. J. Hicks.

St. Louis, Mo.,
April, 1943.

PREFACE TO THE FIRST EDITION

This text has been written especially for radio servicemen, present and future. The use of mathematics has been reduced to a minimum. Fundamental principles are carefully explained and then the application of these principles to various components of radio receivers is discussed. Thus the student gains a knowledge of how and why various circuits operate. The text then goes one step farther in giving definite instructions for performing all the more complicated servicing procedures.

Test equipment is thoroughly discussed and design data for certain types are given. The last chapter is included to aid the student in getting and retaining business. The appendix is intended as a means of ready reference to data frequently desired by servicemen. The extensive index is designed to simplify finding the reference to any topic.

The style and content of the whole text are the outcome of the author's ten years of experience in teaching men engaged in radio service work, sound school for motion-picture operators, and vocational school pupils.

The author wishes to express his appreciation of the most helpful assistance of Mr. Oscar Gotsch, Electrical Instructor at the Hadley Technical High School, in preparing the manuscript.

H. J. Hicks.

St. Louis, Mo.,
March, 1939.

CONTENTS

PRINCIPLES AND PRACTICE OF RADIO SERVICING

INTRODUCTION

Modern receivers have little in common with the receivers that were popular five years ago. The modern receivers cover a much broader band, which may include all frequencies between 550 kc. and 60 mc. Automatic volume control, tone control, both manual and automatic, interstation noise-suppression circuits, volume-expanding circuits, and automatic-tuning circuits have been incorporated in the receivers so that the resultant circuit shows little if any relationship to its predecessor. The introduction of frequency modulation has made the situation ever more complicated. The superheterodyne circuit has become practically standard except for the smallest of the midgets, but even this circuit is so changed that it resembles the original only in the fundamental theory behind it.

These changes have affected the serviceman in many ways. They have totally eliminated the possibility of anyone with only a superficial knowledge of electricity and a tool kit consisting of a screw driver, a pair of pliers, and possibly a voltmeter being able to handle modern service work. This has been a benefit to the servicemen as a group, for it has eliminated a great many of the incompetent, underequipped men who were doing so much damage to the sets they worked on that the whole class of servicemen were rapidly getting the reputation of fakirs and "gyp artists." In order to service the modern radio set, the serviceman must invest a considerable amount of money in test equipment and must have a broad and thorough knowledge of electrical and radio theory or all the test equipment ever made will not enable him to handle his work satisfactorily. The modern serviceman has considerable time and money invested in his training and service equipment. This fact separates him from the shift-

less "odd-jobs" man group and forces him to adopt more businesslike methods if he is to be successful. He must learn how to figure the actual cost of making a repair, how to allow for depreciation on his test equipment, how to determine just which phase of his work is the most profitable, how to get the most from advertising, and many other details of modern business practice.

It has been mentioned that technical training is necessary in order to use modern test equipment. Technical training has other advantages also. It enables the serviceman to select equipment that will have the longest useful life from the standpoint both of wear and of obsolescence. Furthermore, it often enables him to modernize his equipment at small cost. All these items add to his net income and for this reason are highly important.

The literature that has been written to aid the serviceman can be divided into two main classes or types. The first type gives long lists of makes and models of receivers with the troubles that are most common to these types and the remedies. This method has some advantages. It enables a repair to be made in a very short time if the trouble is listed. The only studying necessary is to learn how to find the required reference. The disadvantage lies in the fact that it is practically impossible to list all of the nearly 2,000 different models now in service. Furthermore, this list would be incomplete by the time it could be published, because of the new models coming out. Another drawback to this method is that it does not give any help on any of the difficulties that have not been listed.

The second method pays little or no attention to the various makes and models but attempts to give a broad knowledge of the underlying principles so that these can be applied to any problem that presents itself. This method does not enable the serviceman to begin to use his new knowledge in so short a time as the first, for it takes time to master the fundamental principles; however, it does prepare the serviceman to handle all kinds of sets either present or future. The same fundamental principles can be applied to the design or modernization of test equipment with much benefit to the owner.

CHAPTER I

FUNDAMENTALS OF MAGNETISM AND ELECTRICITY

Fundamentals of Magnetism.—A knowledge of the laws of magnetism is necessary if the theory and operation of power and audio transformers, auto B power packs, electric motors, generators, relays, microphones, speakers, etc., are to be understood.

Permanent Magnets.—Permanent magnets have the ability to retain their magnetism over long periods of time. This is especially true if their poles are always connected by a piece of soft iron known as the "keeper." For this reason, the magnets from any piece of equipment should never be left without a keeper while the equipment is being repaired. Cobalt steel, Alnico, and Nipermag magnets are an exception to this rule. There are always two places on a magnet where the magnetic effect is concentrated. These places are known as the "north" and "south" poles. The poles are named north and south because one end of the needle of a magnetic compass, which is a bar magnet, points toward the North and the other end toward the South. The end that turns toward the North is the north-seeking pole, or simply the north pole. The north and south poles of magnets other than a compass can be determined by the use of a compass and the laws of magnetism given below. Some permanent magnets are laminated. This construction increases the strength of the magnet without increasing the size.

Laws of Magnetism.—Whenever a magnet is brought near a bar magnet that is suspended horizontally by a thread, the following effects will take place:

1. Like poles repel each other.
   Two north poles repel each other.
   Two south poles repel each other.
2. Unlike poles attract each other.
   A north pole attracts a south pole and vice versa.

These two statements are the laws of magnetism.

Magnetic Field.—A magnetic field is the space surrounding a magnet in which magnetic effects can be found. The magnetic theory states that in the field there are lines of force. The

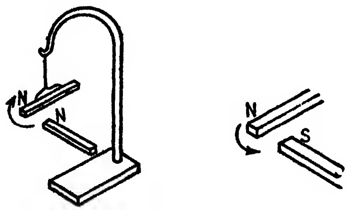


FIG. 1.—Attraction and repulsion of magnetic poles.

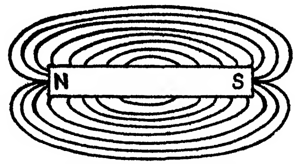


FIG. 2.—Magnetic lines of force about a bar magnet.

number of these lines depends on the strength of the magnet. The position of the lines of force around a bar magnet is shown in Fig. 2.

The lines of force are assumed to issue from the north pole of the magnet, travel to the south pole through the surrounding medium, and return to the north pole through the magnet.

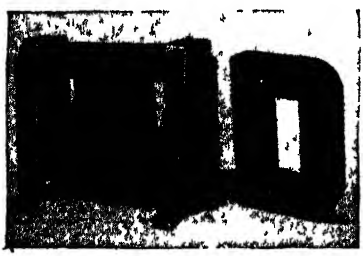


FIG. 3.—Two types of transformer cores.

Magnetic Flux.—A bundle or group of lines of force is called a "magnetic flux."

Magnetic Circuit.—The path followed by the magnetic flux is called the "magnetic circuit." It is always a closed path. The presence of iron or steel in this path greatly aids the flow of the lines of force. For some purposes, a complete magnetic path

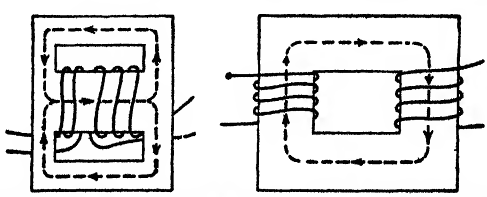


FIG. 4.—Magnetic circuits in two types of transformers.

of iron is provided. In other cases, where it is desirable to limit the flux, a portion of the path is left open or is filled with some nonmagnetic material, such as fiber, paper, wood, or brass.

Diagrams illustrating some of the varieties of magnetic circuits are shown in Figs. 4, 5, and 6.

Permeability.—The permeability of a substance is a measure of the ease with which magnetic lines of force can flow through it. High permeability indicates that lines of force flow through the substance easily, whereas low permeability indicates that they flow through with difficulty.

Fundamentals of Electricity.—There are two types of electrical charges or quantities of electricity, positive and negative. These operate under practically the same laws as magnetic poles. Like charges repel each other, and unlike charges attract each other.

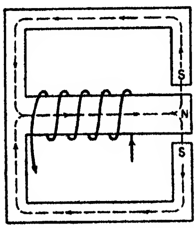


Fig. 5.—Magnetic circuit of a dynamic speaker.

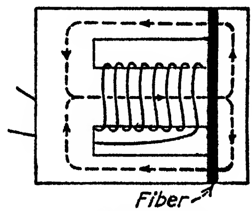


Fig. 6—Magnetic circuit in a choke coil.

The Atomic Theory.—A conception of modern electrical theory demands at least an elementary knowledge of the atomic theory. This theory has been modified several times to make it conform to new facts as they are discovered, and there is a possibility that further changes will have to be made. However, it offers a satisfactory explanation for many phenomena that otherwise could not be explained easily. To date, nothing has been discovered which would tend to prove that the theory as a whole is false. The theory is this: There are a number of materials, called "elements," which have never been separated or divided into other distinct substances. Iron, copper, nickel, hydrogen, and oxygen are some of the elements that have been isolated. The smallest imaginable part into which one of the elements can be separated is an "atom." Materials other than elements are called "compounds" because they are composed of two or more elements. Water is a compound consisting of two atoms of hydrogen and one of oxygen. The smallest portion of a compound is called a "molecule."

For a long time, the atom was supposed to be the smallest particle of matter. Recent discoveries show, however, that this is far from true. The theory, therefore, has been modified so that it now states that the atom is composed of a central mass, or nucleus, called the "proton," around which are circling one or more particles called "electrons." The proton has a positive charge. Electrons are negative charges. The combined negative charges of the electrons just equal the positive charge of the proton under normal conditions. The atom, therefore, under normal conditions, shows no charge because the positive and negative charges neutralize each other. Very recent discoveries have added "neutrons" (particles with no charge) and "positrons" (particles similar to electrons except that they have a positive charge) to the composition of the atom. Very little is known about these recent discoveries.

The structure and the action of the atom are very much like the structure and action of the solar system. The sun corresponds to the proton, or central portion, whereas the planets—the earth, Mars, Jupiter, Saturn, Plato, etc.—correspond to the electrons. In the case of the solar system as well as the atom, the planets or the electrons revolve about the central part in various orbits, some of them close in to the center and others farther away. They do not all have the same plane of rotation; some revolve in a horizontal plane, some in a vertical, and some in a tilted plane.

An increase in temperature causes the electrons to increase the speed of their rotation about the proton. At high temperatures, the speed may increase to such an extent that some of the electrons are thrown out of the atom. This accounts for the electron emission in vacuum tubes. Electrons may also be removed from an atom by the attraction of a positive charge. Atoms that have lost one or more electrons will have an excess positive charge. In this condition, they are called "ions" and the substance is said to be ionized. Ions, being positively charged, are attracted by any negatively charged body.

Electrical Current.—The movement of electrons due to the attraction of a positive charge constitutes an "electric current." There is considerable confusion at the present time concerning the direction of the flow of electric current. Before electrons were discovered, electric current was supposed to flow in the

external circuit, *i.e.*, outside the source of current, from positive to negative. Electrons, however, flow from negative to positive. It is, therefore, necessary, because of this discrepancy, to state definitely which concept is used when discussing problems involving the flow of current. In this text the term "current" or "electron flow" will be used to indicate which concept is meant.

Direct Current.—Direct current (abbreviated d-c) always flows in the same direction in a circuit. Batteries deliver this type of current.

Pulsating Current.—When the amount of a direct current flowing in a circuit varies either regularly or irregularly, it is called "pulsating current." Many of the currents found in radio sets are pulsating.

Alternating Current.—Alternating current (abbreviated a-c) flows first in one direction, stops, flows in the opposite direction, stops, and then repeats the performance. The current does not rise immediately to its full value but increases and decreases at a rate that is approximately a sine curve or a combination of several of them. A simple sine curve is shown in Fig. 7.

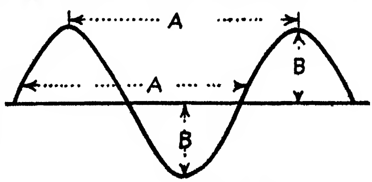


FIG. 7.—A sine wave.

Cycle.—A cycle is one complete performance, as previously outlined. A cycle of a sine curve is indicated by *A* in Fig. 7.

Frequency.—The number of cycles per second is known as the "frequency" (abbreviated f) of the current. The frequency of ordinary house current is 60 cycles per second. Frequencies used on power and light circuits, *viz.*, 25, 40, and 60 cycles, are often called "commercial frequencies." Frequencies between 20 and 15,000 cycles, if fed into a loud-speaker, will produce musical notes that the human ear can detect. These frequencies, therefore, are known as "audio frequencies" (abbreviated a-f). Frequencies between 25,000 and 6,000,000,000 cycles are used in radio transmission and reception and are known as "radio frequencies" (abbreviated r-f).

Harmonic Frequencies or Harmonics.—Harmonic frequencies are always some multiple of the original frequency, which is called the "fundamental." Thus the harmonics of a 60-cycle fundamental would be

60 × 2 = 120 cycles, known as the 2d harmonic
60 × 3 = 180 cycles, known as the 3d harmonic
60 × 4 = 240 cycles, known as the 4th harmonic
60 × 5 = 300 cycles, known as the 5th harmonic

Occasionally the term "subharmonic" is used to denote a frequency found by dividing the fundamental by some number; thus 600 kc. would be a subharmonic of 1,200 kc.

Kilocycle.—The large numbers involved when dealing with radio frequencies led to the adoption of a larger unit, called the "kilocycle" (abbreviated kc.), which is equal to 1,000 cycles. The unit megacycle (abbreviated mc.) is also used. A megacycle is equal to 1,000,000 cycles. For example,

5,000,000 cycles = 5,000 kc. = 5 mc.

Amplitude.—Amplitude is the amount the curve swings either side of the zero line. It indicates the maximum value of the current, voltage, or whatever the curve represents. The amplitude is indicated by B in Fig. 7. This is called the "peak value" of the wave.

The Volt.—A volt is a unit of pressure. Voltage is the force that causes current to flow, and it is similar to the unit "pounds per square inch" used in water systems. In a water system, the higher the pressure, the faster the water will flow. Similarly, in an electrical system, the higher the voltage, the faster the current will flow.

The Ampere.—An ampere is a rate of flow of electrical current, and it is similar to the unit "gallons per second" used in a water system. Notice particularly that it is not just a quantity, like gallons, but a rate of flow, like "gallons per second." An ampere is too large a quantity to use to express most of the values of current that are encountered in radio-receiving work, and so the milliampere (abbreviated ma.), which is one-thousandth (0.001) of an ampere, and the microampere (abbreviated μa), one-millionth (0.000001) of an ampere, are used. The definition of an ampere, as applied to alternating current, states that it is the rate of flow of alternating current that will have the same heating effect as 1 amp. of direct current. Obviously, this could not be the peak value but would be some lesser value so that the peaks could compensate for the two periods during the cycle when the value was zero. This value is called the "effective

value," or the r.m.s. (root-mean-square) value. For a sine wave, it is 70.7 per cent of the peak value and is the value indicated on ordinary a-c meters. The peak value of a sine wave can be found by multiplying the meter reading (effective value) by 1.414. The term "average value" is used to designate the value of steady direct current that would produce the same heating effect as some value of pulsating current under discussion.

Ohms.—An ohm is a unit used to measure the opposition that a circuit offers to the flow of current. There is no similar unit used in water systems. For large values, the unit megohm, which is equal to 1,000,000 ohms, is used. The symbol ω (Greek small-letter omega) is used to designate ohms and Ω (Greek capital omega) for megohms. Both of these symbols are used for ohms in some circuit diagrams. The purpose of the resistor shows whether the value is in ohms or megohms.

Mhos.—Since an ohm is a unit of resistance, or the opposition to the flow of current, the mho (ohm spelled backward) would be the unit indicating the ease with which current can get through a circuit. The letter g is used to represent mhos. Conductance is the reciprocal of the resistance, which expressed as a formula is $g = \frac{1}{R}$. It is also true that $R = \frac{1}{g}$. From these formulas it follows that if $R = \frac{E}{I}$ then $g = \frac{I}{E}$. This last conception of conductance is helpful in understanding the terms "transconductance" and "conversion conductance" as applied to tubes in Chap. III.

Ohm's Law.—The three units just discussed, *viz.*, volt, ampere, and ohm, are related to each other as shown in the following formulas. In reality, these are only different versions of the same one.

$$E = IR \tag{1}$$

$$I = \frac{E}{R} \tag{2}$$

$$R = \frac{E}{I} \tag{3}$$

in which E represents volts, I represents amperes, and R represents ohms.

A great majority of the mathematical problems a serviceman encounters can be solved by the use of these formulas.

Watts.—Power in electrical circuits is measured in watts (abbreviated W.). The units milliwatt $\left(\frac{1}{1,000}\text{ watt}\right)$, microwatt $\left(\frac{1}{1,000,000}\text{ watt}\right)$, and kilowatt (1,000 watts) (abbreviated kw.) are also in common use. One horsepower is equivalent to 746 watts. In d-c circuits, the power can be found by multiplying the volts by the amperes or in the form of a formula $W = EI$. Since $E = IR$, this can be written $W = IRI$ or I^2R. Since $I = \frac{E}{R}$ the formula $W = EI$ can also be written $W = E \times \frac{E}{R}$, or $W = \frac{E^2}{R}$. Any of these formulas can be used in determining the wattage rating required for a resistor. For example, if it is known that a resistor is 2,000 ohms and that 4 ma. flows through it, the wattage rating of the resistor must be

$$W = I^2 \times R \qquad \text{or} \qquad 0.004 \times 0.004 \times 2,000 = 0.032 \text{ watt}$$

If it is known that the voltage across the resistor is 8 volts and the current through it 4 ma., the required wattage rating can be obtained from the formula $E = EI$, or

$$W = 8 \times 0.004 = 0.032 \text{ watt.}$$

If only the voltage across the resistor and its resistance are known, the formula $W = \frac{E^2}{R}$ can be used.

$$W = \frac{8^2}{2,000} = \frac{64}{2,000} = 0.032 \text{ watt.}$$

Series Circuits.—When all the pieces of equipment in a circuit are connected, one after the other, as shown in Fig. 8, they are connected in series.

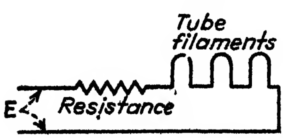


FIG. 8.—A series circuit.

Note that in this circuit any current that passes through one piece of equipment must pass through all of them, or, in other words, the current is the same in all parts of the circuit. The voltage E, impressed across the ends of the circuit, is divided between the various pieces of equipment. Each one has some of the voltage across its terminals, but not necessarily the same

amount as the others. The voltage across any piece of equipment is always equal to the current through it multiplied by its resistance. This relation is indicated by the formula $E = IR$. The total resistance in a series circuit is equal to the sum of the resistances of the various parts. The current is equal to the voltage across the ends of the circuit, divided by the total resistance in the circuit, as indicated by the formula $I = \frac{E}{R}$.

Parallel Circuits.—When each piece of equipment is connected across the line, as shown in Fig. 9, they are said to be connected in parallel. When only two pieces of equipment are connected across the line, one is said to "shunt" the other. In a parallel circuit, each piece of equipment receives full line voltage.

The total current I is found by adding the current taken by each of the pieces of equipment. The total resistance R of the

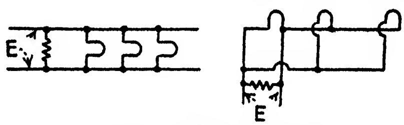


FIG. 9.—Parallel circuits.

circuit can be found from the formula $\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$, in which R is the total resistance and r_1, r_2, and r_3 are the resistances of each of the branches. This is known as the conductance method of finding the resistance. When only two resistors are in parallel, the total resistance $R = \frac{r_1 \times r_2}{r_1 + r_2}$. For example, in a circuit having resistors of 2 and 3 ohms in parallel, the total resistance $R = \frac{2 \times 3}{2 + 3}$ or $\frac{6}{5}$ ohms $= 1\frac{1}{5}$ ohms.

Problem to Demonstrate Use of the Formula.—In the diagram, Fig. 9, assume that the filaments are each 20 ohms and the resistor 10 ohms. The first formula must be used to find the total resistance in the circuit. Substituting the above values in this formula gives $\frac{1}{R} = \frac{1}{10} + \frac{1}{20} + \frac{1}{20} + \frac{1}{20}$. Adding the fractions at the right of the equality sign gives $\frac{1}{R} = \frac{5}{20}$, or $\frac{1}{4}$. Turning the whole expression upside down gives $\frac{R}{1} = \frac{4}{1}$, or $R = 4$ ohms.

In a parallel circuit, when all the branches have the same resistance, the total resistance can be found by dividing the resistance of one branch by the number of branches.

Parallel-series Circuits.—Speakers are often connected in a parallel-series circuit. Figure 10 gives the diagram of one of the many possible variations of this circuit. It shows two series groups of three speakers connected in parallel. To find the total resistance of this circuit, first determine the resistances of the series groups. If the resistances of the speakers were assumed to be 10 ohms each, the resistance of each group would be 3×10 or 30 ohms. The total resistance of the two 30-ohm groups in parallel can be found from the formula $R = \frac{r_1 \times r_2}{r_1 + r_2}$, which becomes $R = \frac{30 \times 30}{30 + 30}$, or 15 ohms.

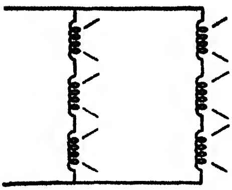


FIG. 10.—A parallel-series circuit.

The following problems are introduced here to illustrate the use of Ohm's law in radio calculations:

Problem 1. To determine the value of a cathode-bias resistor to obtain the proper grid bias for a tube. A type 45 tube will be used in the example.

a. Consult a tube chart to obtain the bias voltage required. This will be the voltage developed across the resistor and will be the E in the formula. From the same chart, obtain the plate current. If the tube has a screen grid or more than one plate, the total current passing through the cathode must be found. This current will be the I in the formula. The type 45 tube requires a 50-volt bias and has a plate current of 34 ma. The formula requires the units to be volts and amperes, and so 50 and 0.034 must be used.

b. Choose the proper formula. Since the resistance is required, the proper formula is $R = \frac{E}{I}$. When the values from the chart are substituted in this formula, $R = \frac{50}{0.034}$ or 1,470 ohms. A 1,500-ohm resistor would be used. This would be an error of 2 per cent, but, since the commercial resistors are accurate to within only 10 per cent, the error is of no consequence. Before the proper resistor can be selected, the wattage required must be determined. The simplest formula to use is $W = EI$, in which E is 50 volts and I is 0.034 amp. The watts W then will be 50×0.034, or 1.7. However, since resistors are rated on their capacity in mid-air, the computed wattage must be doubled at least, because of the lack of ventilation under the chassis. For this reason, a 5-watt resistor would be used.

Problem 2. To determine the value of the resistor to use in series with the line in a set that has series filaments. In this example, the set has three 6-volt tubes and one 25-volt tube. All the tubes require 0.3 amp. The set is to be used on a 115-volt line.

a. Find the total voltage required by all the tubes. Since it is a series circuit, the total voltage is the sum of the voltages of the various tubes $6 + 6 + 6 + 25 = 43$ volts. The rest of the line voltage, or $115 - 43 = 72$ volts, must be across the resistor. The E in the formula is 72 volts and the I is 0.3 amp.

b. The proper formula to use is $R = \frac{E}{I}$ and, by substituting the values determined previously, $R = \frac{72}{0.3}$ or 240 ohms. The wattage of this resistor can be found as in the previous example. Here E is 72 volts, and I is 0.3 amp., and so W or $E \times I$ is $72 \times 0.3 = 21.6$ watts. The results indicate that a 50-watt resistor would be suitable.

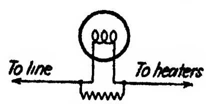


FIG. 11.—Circuit diagram of a shunting resistor for a pilot light.

Problem 3. To determine the resistance and wattage rating of a resistor shunting a pilot light. In a-c d-c sets it is usually necessary to place a resistor across the pilot light because none of the pilot lights require 0.3 amp., which is almost standard for heater current in these sets. Pilot lights require either 0.15 or 0.25 amp. The shunt resistor is designed to carry the additional current required by the tubes. The circuit is shown in Fig. 11.

To illustrate the mathematical procedure we shall assume that this pilot light requires 6.3 volts and 0.25 amp. and that the heaters require 0.3 amp.

a. Find the current in the resistor. This will be the difference between the heater current and the pilot-light current, $0.3 - 0.25 = 0.05$ amp.

b. The voltage across the resistor will be the same as that across the lamp or 6.3 volts.

c. The resistance then may be found from the formula

$$R = \frac{E}{I} \qquad \text{or} \qquad \frac{6.3}{0.05} = 126 \text{ ohms.}$$

d. The wattage rating will be $W = EI$ or $6.3 \times 0.05 = 0.315$ watt. This resistor will frequently be found in "plug-in" or ballast resistors.

Electromagnetism.—An electromagnet consists of a soft iron core around which is wound a number of turns of insulated wire. When electric current is passed through the wire, the core has all the characteristics of a permanent magnet. However, the electromagnet has many advantages over the permanent magnet. One of these is the fact that the magnetism can be created and destroyed by simply starting and stopping the current. The strength of the magnetism can also be controlled by regulating

the flow of current or the number of turns of wire in the coil. An increase in either of these quantities will increase the intensity of the magnetism. Reversing the current reverses the magnetism also.

The Right-hand Rule.—This simple rule is very convenient when it is necessary to determine which is the north pole of an electromagnet. The rule is simply this: Grasp the coil with the right hand with the fingers pointing in the direction that the current is flowing around the coil. The thumb will then point in the direction of the north pole.

Magnetic Saturation.—The strength of the magnetic field about an electromagnet increases as the number of turns or the current in the coil is increased until the core can carry no more lines of force. When this condition exists, the core is said to be "saturated." Any increase in the amount of current flowing in the coil above that necessary to saturate the core will have very little effect on the strength of the magnetism. This fact will have a definite application in a discussion of distortion caused by the saturation of the cores of transformers used in amplifiers.

Field about a Wire.—It is not necessary to wind a wire around an iron core to produce magnetic effects, as this procedure simply intensifies the effect. Any wire carrying electric current is surrounded by a magnetic field. This field is responsible for many of the difficulties experienced with hum and howling in radio sets.

The right-hand rule can also be applied to the field about a wire. If the right hand is placed around the wire with the fingers pointing in the direction of the field about the wire, then the thumb will be pointing in the direction that the current is flowing or, if the direction of the current is known, then the direction of the field can be determined.

Generation of Electric Current. 1. *By Chemical Means.*—The current obtained from a battery is the result of certain chemicals combining with others. In the case of dry cells and air cells, the battery is dead and useless when all the chemicals have combined. Dry cells are not actually dry, but moist; and, if left for several months without use, they lose their moisture. The loss of this moisture, combined with the chemical action that takes place at a very slow rate even when the battery is not in use, renders

the battery useless. The chemicals in storage batteries are of such a nature that they can be restored to their original condition by passing a current through the battery from the positive pole to the negative pole when the battery is discharged. Much noise can be caused in radio sets or public-address equipment by chemical action (corrosion) around such places as battery terminals, fader contacts, and wire-wound volume controls.

2. *By Mechanical Means.*—Electric current can also be generated in a wire by causing it to cut magnetic lines of force. This can be accomplished by having the wire fixed in position and moving the magnetic field or by using a fixed magnetic field and moving the wire through it. The first method can be illustrated by using a zero-center milliammeter connected to the secondary of an old audio transformer from which the core and the primary have been removed. If the end of a bar magnet is suddenly plunged into the center of the coil, the meter will indicate the passing of a momentary current by the swing of the needle to one side. If the magnet is suddenly removed from the coil, a momentary current in the opposite direction will be indicated. By continually moving the end of the magnet in and out of the coil, an alternating current can be generated. The results are the same when the magnet is stationary and the coil is moved. It is important to understand clearly that no current is generated in a wire in a magnetic field unless it is cutting lines of force. An electromagnet may be substituted for the bar magnet, and identical results will be obtained.

A magneto generates current by moving a coil of wire in the field of a permanent magnet, whereas a dynamo generates current by moving coils of wire in the field of electromagnets. Alternating current is usually generated by using stationary coils and a moving electromagnetic field.

3. *By a Varying Flux.*—Induction coils and the transformers used in the vibrator type of B power supply use this method of generating current. An induction coil consists of an iron core on which two coils are wound, one over the other. The primary, or inner coil, and a battery are in a series with a device that rapidly interrupts the current. As the current starts to flow, a magnetic field spreads out from the primary that cuts the turns of the secondary, or outer coil, and generates a voltage in them.

When the current in the primary is interrupted, the magnetic field collapses and cuts the turns of the secondary in the opposite direction, generating a voltage in them which is in the opposite direction from the first voltage. Thus, an interrupted direct current in the primary generates an alternating voltage in the secondary so that alternating current will flow if the circuit is closed.

If alternating current is passed through the primary coil of a transformer, alternating voltage will be generated in the secondary coil, for it must be remembered that alternating current stops and starts twice in each cycle. It will be seen, therefore, that the fundamental principle of a transformer and the induction coil is the same.

When one of two parallel wires is carrying alternating or pulsating current, the action between them is exactly like that between the primary and secondary of the induction coil. This accounts for the disturbance picked up by an antenna [illegible] parallel to a power line and also for the feedback caused b[illegible] and plate leads and other wires in a set that are cabled together.

4. *By a Difference in Temperature.*—Electric current may be generated by heating the junction of two different metals. Any two different metals may be used. This type of junction is known as a "thermocouple." It is the fundamental part of the operating mechanism of the thermocouple-type meter. The action is known as the "thermoelectric effect." A simple thermocouple to demonstrate this effect can be made by twisting the ends of two pieces of wire, one iron and the other copper, together and connecting the free ends to a milliammeter with a scale not over 0 to 5 ma. If a lighted match is held under the junction of the wires, the meter will indicate that current is being generated. This thermoelectric effect sometimes causes trouble in radio sets when a soldered joint (composed of copper, lead, and tin) is heated by a near-by resistor or transformer. To avoid the introduction of voltage that will cause noise in public-address amplifiers having high amplification both the stationary and moving elements of all movable contacts, such as switches and volume controls, must be of the same material. The effect may also cause trouble with shunts on meters if they warm up appreciably. The voltage generated may cause the meter to r[illegible] high or too low, depending on its direction. In adjusting the

shunts on milliammeters, the heat from the soldering iron on the joints may cause the meter to read several milliamperes.

5. *By Bending Crystals.*—It has been found that if slabs or slices of certain crystals, especially quartz and Rochelle salt, are cut in certain ways, they have the property of generating voltages on their surfaces when they are bent. Connection is made by cementing tin foil on the sides. These crystal slabs are usually square or oblong. They are fastened at three corners. In the crystal microphone the fourth corner is fastened to a diaphragm. The sound waves vibrate the diaphragm which bends the crystal and produces voltages which are fed into an amplifier and then changed to sound by a loud-speaker.

The crystal phonograph pickup is practically the same. The needle is connected to the crystal in such a way that it bends the crystal as it follows the grooves in the record.

6. *Photoelectric Effect.*—It has already been shown that elec-[illegible] are given off by hot substances. Certain substances also [illegible] off electrons when light strikes them. Cesium, potassium, sodium, lithium, and rubidium will give off electrons if they are illuminated with visible light. Cerium, thorium, uranium, cadmium, zirconium, and titanium emit electrons when ultraviolet light falls on them. This property is used in the photocell popularly known as the "electric eye." In this cell a plate of metal is covered on one side with a coating of any one of the above materials. The choice of material depends upon the type of light that is to be used. The plate is usually formed into a half cylindrical shape. A stiff wire at the axis or center of the cylinder has a positive voltage on it to attract the emitted electrons. This is the reverse of the conditions in a thermionic tube, where the emitter or cathode is in the center and the plate or anode, which is positive, attracts the electrons outward.

In the photocell the emitter or cathode is a plate and the anode is at the center. The electrons are attracted toward the center.

7. *Friction.*—Very substantial voltages can be built up by rubbing one substance against another. Lightning is caused by one mass of air or a cloud passing another mass of air or another cloud. Severe shocks are sometimes received by touching a metallic object such as an elevator call button after walking over [illegible] carpets. The high voltages used in atom smashers are sometimes generated by friction belts.

REVIEW QUESTIONS

1-1. What are magnetic poles?
1-2. Give the laws of magnetism.
1-3. Define:
a. Magnetic field.
b. Magnetic flux.
c. Magnetic circuit.
1-4. Make a drawing showing the magnetic circuit of a transformer.
1-5. Define permeability.
1-6. Give the laws governing electrical charges.
1-7. Define:
a. Element.
b. Compound.
c. Atom.
d. Molecule.
1-8. What polarity has the
a. Atom?
b. Proton?
c. Electron?
d. Ion?
1-9. (*a*) What is the effect of heat on an atom? (*b*) Where is this effect used in radio?
1-10. What is meant by ionization?
1-11. Define:
a. Electrical current.
b. Direct current.
c. Pulsating current.
d. Alternating current.
1-12. Define:
a. Cycle.
b. Frequency.
c. Harmonics.
d. Kilocycle.
1-13. What is meant by amplitude?
1-14. What is meant by 1 amp. a-c?
1-15. Define:
a. Peak volts.
b. R.m.s. value.
Give the formulas to change from one to the other.
1-16. What is (*a*) an ohm? (*b*) A mho?
1-17. State three forms of Ohm's law.
1-18. State three forms of the formula for watts.
1-19. In a series circuit the ______ is the same in all parts.
1-20. In a series circuit the sum of all ______ or ______ is equal to the total ______ or total ______.
1-21. In a parallel circuit the sum of all the ______ is equal to the total ______. In a parallel circuit the ______ is the same in all branches.

1-22. What is meant by the expression "a resistor shunts the meter"?

1-23. Give the formula for R in a parallel circuit with all the resistances unequal.

1-24. Give the short cut for finding the total resistance of two resistors in parallel.

1-25. Give the short cut for finding the total resistance of several equal resistors in parallel.

1-26. What is meant by a parallel series circuit?

1-27. What is an electromagnet?

1-28. What factors determine the strength of the magnetism?

1-29. What determines the direction of the magnetic field?

1-30. Give the right-hand rule for electromagnets.

1-31. What is meant by magnetic saturation?

1-32. Give the right-hand rule for the magnetic field about a wire.

1-33. Name seven methods of generating voltages.

CHAPTER II

FUNDAMENTALS OF RADIO

Radio Wave.—Each cycle of current in a transmitter sends out one radio wave. This wave consists of electrostatic and magnetic lines of force. Radio, light, radiant heat, and X rays are all waves of the same type; they differ only in wave length. This accounts for the fact that the shorter radio waves, which have wave lengths nearest to the wave lengths of light, behave very much as light waves do. They can be reflected by mirrors or formed into a beam similar to a searchlight beam by the use of similar equipment. The name "quasioptical," which means "like light," has been given to these waves.

Speed of Radio Waves.—Radio waves travel at the rate of nearly 300,000,000 meters, or 186,000 miles, per second, which is also the velocity of light. A meter is 39.37 in. long. Very recent experiments seem to indicate that the daylight velocity is different from the velocity at night and that other conditions may have an effect on the velocity.

Wave Length.—If radio waves travel at the rate of 300,000,000 meters per second, a single wave that started at the beginning of a second would be 300,000,000 meters from the antenna at the end of a second. Other waves generated during the second would fill all the space between the first wave and the antenna. The number of waves in this space would depend on the number sent out per second or, in other words, on the frequency of the transmitter. If the frequency were 1,000 kc., the number of waves in the 300,000,000 meters would be 1,000,000. The length of each wave, then, would be $\frac{300,000,000}{1,000,000}$ or 300 meters. The relations between wave length, frequency, and the velocity of light can best be expressed by the following formulas:

$\lambda = \frac{V}{f}$, in which λ (Greek letter lambda) is the wave length in meters, V is the velocity of light in meters per second, and f is the frequency in cycles per second. By simple algebra, this formula

can be changed to the form $f = \frac{V}{\lambda}$, which indicates that the frequency of a station can be found by dividing the velocity of light by the wave length of the station.

The Kennelly-Heaviside Layer.—It has been definitely established that the ultraviolet radiation from the sun forms an ionized layer approximately 50 miles above the earth. This layer is the cause of many of the peculiarities of radio transmission and reception. Any waves with a wave length above 10 or 12 meters are refracted (bent) by this layer; the longer the wave length, the more they are bent. The longer wave lengths are bent so sharply that they return to the earth at relatively short distances. The shorter wave lengths are bent the least and so return to the earth at great distances, if at all. This accounts for the great distances from which short-wave radio signals can be heard. Commercial stations use the wave lengths best suited for the distances over which they are transmitting. Thus, if a shore station was communicating with a ship just leaving port, a relatively long wave length would be used; as the ship increased the distance between it and the shore station, shorter and shorter wave lengths would be used. The absence of daylight changes the conditions in the ionized layer, which in turn changes the wave lengths for best results. This at least partly explains why certain stations can be heard only at certain periods during the 24 hr.

Fading.—The energy radiated from an antenna follows two paths: one known as the "sky wave" has been discussed in the preceding paragraph; the other follows a path along the surface of the earth. The lengths of these two paths may be such that the two waves reach the receiver in synchronism, in which case they will reinforce each other and provide a strong signal. However, some change in the ionized layer may change the length of the path followed by the sky wave so that it reaches the receiver out of step with the ground wave. In this case, the waves oppose each other and very weak signals result. The continual variations of the ionized layer, therefore, cause fading or a change in the signal strength. The main purpose of automatic volume-control (abbreviated a.v.c.) circuits is to overcome this disagreeable feature of radio reception.

Inductance.—In the section explaining the generation of electric current, the generation of a voltage in a coil by the flux

from another coil was explained. The same action takes place between the turns of a single coil. When the flux created by one turn of wire cuts the other turns, a voltage is generated in them. The lines of force move outward when the current increases and inward when the current decreases. In either case, the voltage generated opposes the action of the voltage that is creating the current. When the current is increasing, the voltage generated opposes the voltage that is causing the current to increase. When the current is decreasing, the voltage generated aids the voltage in maintaining the current at its original value.

Inductance Defined.—That property, or ability, of a circuit to *oppose any change* in the current flowing in it is called "inductance." Inductance is usually considered to be the property of a coil; however, even a straight wire has some inductance. This fact is important when high frequencies are used. In circuits for very high frequencies, the inductance of the leads is often high enough for tuning purposes without the use of a coil. The inductance of a coil depends on many things. The more important are the number of turns of wire, the spacing of the wire, the diameter of the coil, the ratio of the length to the diameter, and, in the case of iron-cored coils carrying both direct and alternating current, the amounts of each type of current.

Inductance is represented by the letter L. It is measured in henrys (abbreviated h.), millihenrys, and microhenrys (abbreviated mh. and μh, respectively). μ is the Greek letter pronounced "mu." 1,000 mh. equals 1 henry; 1,000 μh equals 1 mh.

Capacity.—The ability to store up electrical energy is called "capacity." Capacity is represented by the letter C. It is measured in farads (abbreviated fd.), microfarads (abbreviated mf., mfd., or μf), and micromicrofarads (abbreviated mmf., mmfd., or $\mu\mu$f). The relation of the units to each other is shown in the following table:

1,000,000 mmf. = 1 mf.
1,000,000 mf. = 1 farad

Condensers.—A condenser consists of two conducting substances insulated or partly insulated from each other. The conducting substances are usually two sheet-metal or foil plates but may be liquids or a piece of wire or spherical knobs. The capacity of a condenser increases as the plates are made larger

or the space between them is made smaller. The capacity of the condenser also depends on the material between the plates.

The dielectric constant of a substance is the number of times the substance would increase the capacity of a condenser if it, instead of air, were used between the plates. Air has a dielectric constant of 1.

Condensers may be divided into the following types according to the kind of insulating material used: air-dielectric condensers, which are usually variable and are used for tuning r-f circuits, mica condensers, paper condensers, and electrolytic condensers.

Where the change of capacity due to humidity, temperature variations, etc., must be reduced to a minimum, air condensers are used. Mica condensers are the next choice in this respect. Mica condensers have the added advantage of being very much smaller and less expensive. Variable mica-insulated condensers are used to tune i-f (intermediate-frequency) amplifiers and as trimmer condensers in r-f circuits.

The electrolytic condenser is very convenient when a large capacity is required in a small space. It is limited in its application to circuits where the polarity is never reversed and where the normal leakage of from 0.05 to 0.1 ma. per microfarad is not objectionable. Electrolytic condensers cannot be used on r-f circuits because they have some inductance due to the way they are wound.

The paper-insulated condenser is very useful in certain circuits in radio and public-address equipment. Its insulation resistance is not so high as that of the mica condenser, and it occupies much more space for the same capacity than the electrolytic. However, it is much cheaper than the mica condenser and can be used on circuits carrying alternating current.

The use of the various types of condensers in a typical radio set is very thoroughly discussed in the following article.[1]

Now let us turn to the circuit of Fig. 14. This is the schematic diagram of a typical all-wave receiver but with only two of the coil sets shown so as not to complicate the drawing too much. The other ranges employ coils and trimmer condensers similar to the two ranges shown. Condensers C1, C2, C7 and C8 are trimmers connected across the r.f. and the first detector coils. The use of mica compression types is nearly universal. (These are illustrated at *A* and *C* in Fig. 12.)

[1] From the *Aerovox Research Worker*, Vol. 8, No. 4.

Slight variations in the capacity will bring the receiver slightly out of line but does not affect the dial setting which is controlled entirely by

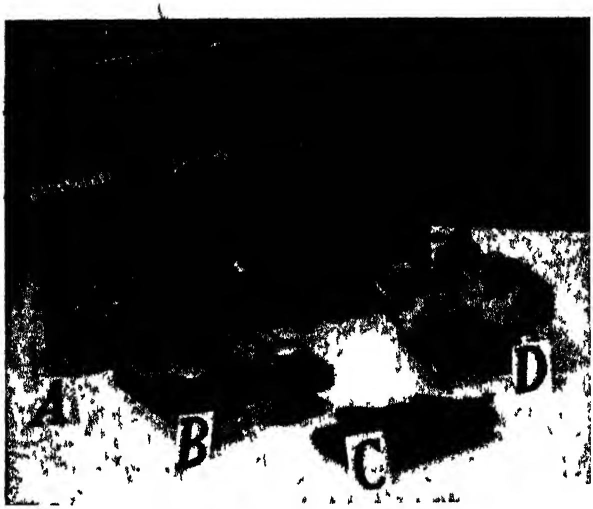


FIG 12 —Variable condensers

the oscillator. Therefore, even if very accurate calibration is required, it is often felt that the added expense of air-dielectric trimmers is not warranted.*

FIG. 13.—Fixed mica and paper condensers.

C4, C14 and C15 are the tuning condensers and these are of course of the customary three-gang air-tuned type. (See *A* in Fig. 12.) C5, C6, C17, C18, and C19 are employed to by-pass r.f. and i.f. currents around resistors. For the average all-wave receiver paper condensers will be employed. (See *L* in Fig. 13.) The value of the condenser depends on the resistance of the circuit to be by-passed and the frequency. The bias resistor of the first r.f. tube is generally a few hundred ohms. The size of the condenser is now usually .1 mfd. This should prove a satisfactory arrangement for most purposes. Some designers of special receivers have gone farther and use sizes of .5 and even 1 mfd.

There are also special cases such as ultra high-frequency receivers which call for smaller condensers due to the higher frequency. Mica condensers are used exclusively for such purposes. (See *I*, *J*, and *M* in Fig. 13.)

Condensers in the plate and screen circuits, such as C6, C17, C18, C22 and C23 are generally used in conjunction with a resistor of 1000 ohms in the plate circuit and many thousands of ohms in the screen circuit. A size of .1 mfd. is often used but some use .05 or even less. The reader will also find designs which omit the filter in one or more stages. Generally some kind of filtering will be required where there are two successive stages working at the same frequency.

C3 and C9 are condensers which serve as filters for the a.v.c. system. They are also in series with the tuning condensers C4 and C15. Therefore it is important that they should not cause any appreciable detuning due to possible variations in their capacity, nor cause any reduction in tuning range and they should be equal if possible. From the standpoint of the design of a.v.c. systems, the leakage resistance should be high. The types used are either paper or mica depending on the required size. If the size of C3 is very much larger than C4, small variations in the capacity do not appreciably alter the capacity of the two in series because it will be smaller than the smallest. On the other hand, if C3 is not very much larger than C4, it becomes important that the value remain the same and that the two condensers in the two stages remain the same. There is also the question of power factor. Since the condenser is used in a tuned circuit, a low power factor is desirable. All the previous considerations would point to the mica condensers as the best solution, but it becomes uneconomical to use it when the size is .05 mfd. Mica condensers of .01 and .015 mfd. are being used in some receivers.

C10, C11, C12 and C13 are the trimmer and padder condensers employed in the oscillator circuit to make it track with the r.f. tuning condensers. When high precision is required air-tuned condensers are desirable but they are not used much except in special receivers for amateurs which employ band spreading. In the majority of cases, condensers with mica dielectric are employed for the purpose. (See *D* in Fig. 12.) The trimmers, C10 and C12 must be variable for all ranges. The padder condensers generally have to be of a rather large size. The required capacity for the broadcast band employing a 456 kc. intermediate frequency is in the neighborhood of 400 mmfd., or slightly more. If the intermediate frequency is 175 kc., the required size is somewhere near 750 mmfd. For the short-wave bands the values become larger, up to 2000 mmfd. and more. In the smaller inexpensive receivers, these padders are often fixed condensers of the mica type and one also encounters fixed paper condensers. Other sets have the mica compression

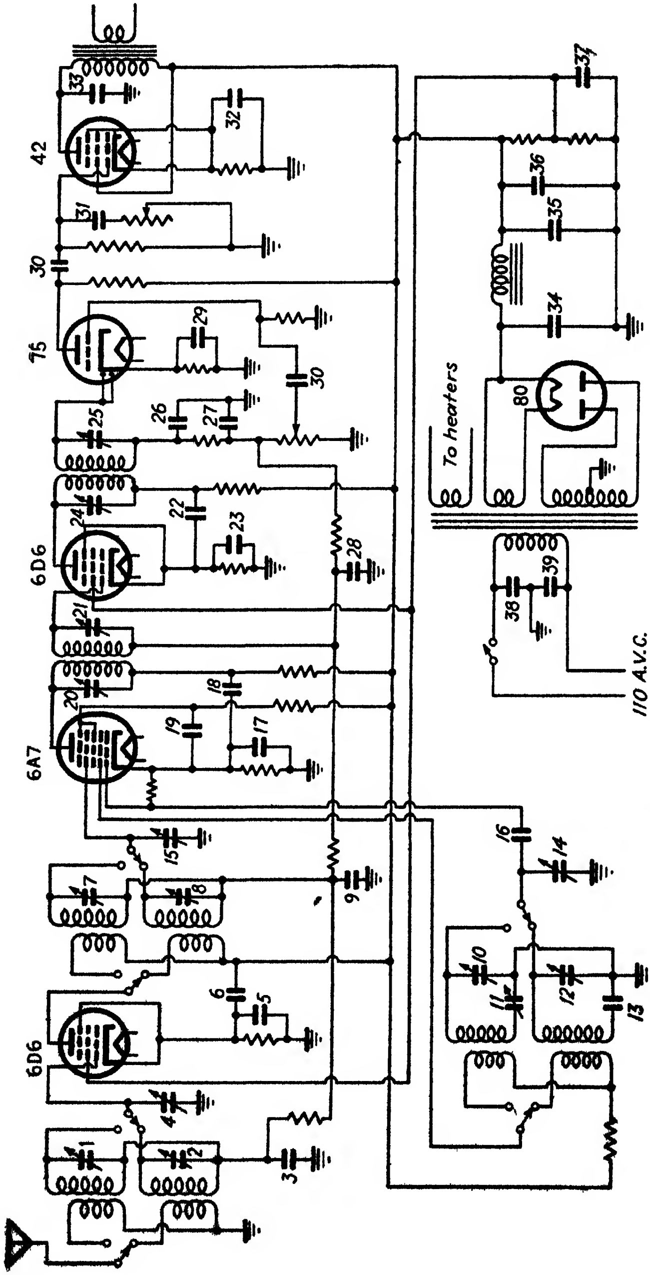


FIG. 14.—Circuit diagram of an all-wave superheterodyne receiver. (Courtesy of the Aerovox Research Worker.)

type for the two highest-wave length ranges and fixed one for the short-wave range. Then there are some designers who use a mica condenser in parallel with a small mica trimmer These arrangements are satisfactory unless very accurate logging is required; in that case the air-tuned padder and trimmer is the only solution.

The grid condenser C16 is always a mica condenser. Now we come to the variable condensers in the i.f. amplifiers C20, C21, C24, and C25. The capacity value of these trimmers is somewhere between 70 and 100 mmfd. as an average. (See *B* in Fig. 12.)

Compression type mica condensers are used for the purpose. In recent years, high quality receivers have been built which employ the air dielectric type in order to obtain greater constancy of adjustment.

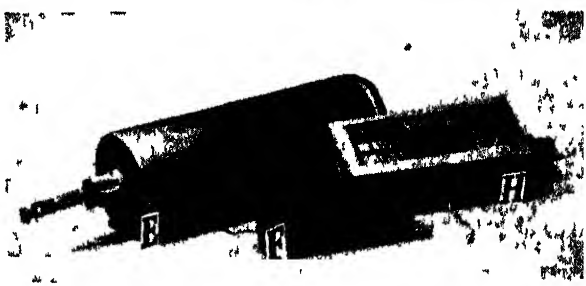


FIG 15.—Wet and dry electrolytic condensers

C28, in the a.v.c. system usually has a value of .05 mfd. and is of the paper type. Since it is used in a high resistance circuit the leakage resistance should be high. C26 and C27 serve to filter the r.f. component from the output of the detector. Since rather small condensers are used here, the mica type is most often employed. The capacity value of these condensers may be .0001 mfd. In these days of high-fidelity receivers it is necessary to make the by-pass condenser as small as possible because the higher audio frequencies might be by-passed too. The trend is at present towards using only one condenser and reducing its size to .00075 or .0005 mfd.

C29 is employed to by-pass audio frequencies because the triode section of the tube is an audio amplifier. Before the advent of high-capacity electrolytic condensers it never was possible to get a big enough condenser so as to amplify the low notes adequately. The bias resistor of the tube is in the neighborhood of 2000 or 3000 ohms. If this is shunted by a 1 mfd. paper condenser which used to be the practice, the impedance of the combination is still over a thousand ohms at 100 cycles. Here indeed the bigger the condenser, the better. The low-voltage high capacity electrolytic serve the purpose admirably. Condensers of 50 mfd. at 50 volts are popular. (See *F* in Fig. 15.)

C30 should be a condenser with a capacity large enough to give proper base response, and it should have a low leakage because leakage will cause a change of bias on the next tube which will destroy the quality and maybe the tube. With the usual sizes of grid-leak, the value of C30 ranges from .1 to .01 mfd. There are very few audio amplifiers which employ larger condensers unless they are designed for special purposes. A good paper condenser will serve.

The tone-control condenser C31 is generally a paper type with a capacity of .05 mfd. or thereabouts. Some different designs are now used which do not employ the variable resistor but use a variable condenser instead; this is then a mica compression type.

C32 is another condenser which must provide an easy path for low frequencies around a low resistance. A large electrolytic condenser with a low voltage rating has to be employed. There are several alternate ways of obtaining the bias for this tube, as described in the previous issues of the Research Worker. The bias can be obtained from a tap on a choke in the negative lead of the power pack. In this case, if the series resistance is high, a smaller paper condenser can be used.

C33 is often found necessary to remove some of the hiss and frying noises in circuits with a pentode output tube. A paper or a mica condenser are found in today's receivers with tubular paper types in the majority.

In the powerpack, C34 and C35 are of the high-voltage electrolytic type. Hardly any receiver in existence uses any other type. (See *E* and *H* in Fig. 15.) Some designers find that the electrolytic condenser does not provide a satisfactory by-pass for r.f. current and wishing to filter the B-supply for disturbances in the line, a paper condenser, C36 is connected across the electrolytic condenser. The hum-voltage passes through the big condenser and the r.f. passes through the smaller paper condenser.

C37 is another condenser which shunts a low resistance. The frequency in question however is high so a paper condenser of .1 or .5 mfd. will be found to work well.

C38 and C39 which filter the line are usually paper condensers with capacities between .1 and .5 mfd. each.

Condensers in Parallel.—The total capacity of condensers in parallel is found by adding the capacities of the separate condensers. When condensers are connected in parallel, each one must stand the full line voltage.

Condensers in Series.—The total capacity of condensers in series is found from the formula $\frac{1}{C} = \frac{1}{c_1} + \frac{1}{c_2} + \frac{1}{c_3}$, in which C

is the total capacity and c_1, c_2, and c_3 are the capacities of the separate condensers. The procedure for using this formula is the same as for using the formula for finding the total resistance of resistors in parallel. The total voltage in the circuit is divided between condensers in series; however, it divides in proportion to their leakage resistance, and therefore one may have more than its share and break down. When this occurs, the full voltage is divided among the remaining condensers, which may result in the failure of the whole group. For this reason, it is not good practice to put condensers in series to obtain a higher voltage rating unless resistors are put in parallel with them.

Reactance.—Both coils and condensers offer opposition to the flow of current. This opposition is measured in ohms and is called the "reactance" of the coil or condenser. "Inductive reactance" (symbol X_L) is the name of the reactance of a coil, and "capacitive reactance" (symbol X_c) that of a condenser. The reactance of a coil expressed in ohms is given by the formula $X_L = 2\pi fL$, in which π (the Greek letter pi) is the quantity 3.1416, f is the frequency in cycles per second, and L is the inductance in henrys. The reactance of a coil is not a fixed quantity, but varies with the frequency of the current passing through it. As the frequency increases, the reactance also increases.

The reactance of a condenser is given by the formula

$$X_c = \frac{1}{2\pi fC},$$

in which π and f are the same as before, and C is the capacity of the condenser in farads. The reactance of a condenser also varies with the frequency; however, it decreases as the frequency increases.

Impedance.—The total opposition to the flow of current in a circuit, due to resistance and inductive and capacitive reactance, is called the "impedance" of the circuit. It is designated by the letter Z. The total impedance of a circuit *cannot* be found by adding the resistance and the reactances, for these do not act in the same direction. In fact, X_L and X_c, if present in equal amounts, cancel each other. In a circuit containing both X_L and X_c, the effective reactance is found by subtracting the

smaller quantity from the larger. The following formulas give the impedance in any circuit containing R, X_L, and X_c:

For a circuit containing only R and X_L, $Z = \sqrt{R^2 + X_L^2}$.
For a circuit containing only R and X_c, $Z = \sqrt{R^2 + X_c^2}$.
For a circuit containing, R, X_L, and X_c,

$$Z = \sqrt{R^2 + (X_L - X_c)^2}.$$

These relationships are shown graphically in Fig. 16.

These formulas will be the foundation of the discussion on tone controls, amplifier-frequency characteristics, frequency-divider circuits for sets having more than one speaker, and many other topics. For this reason they should be memorized thoroughly.

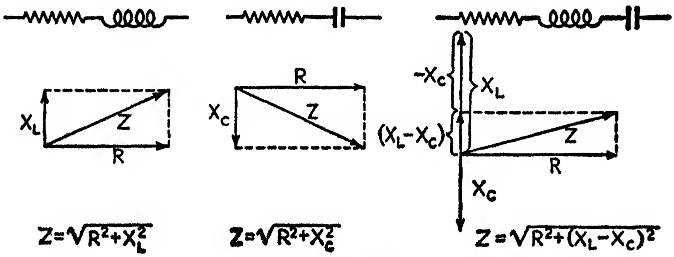


Fig. 16.—Impedance diagrams.

Phase.—In an a-c circuit containing resistance only, the voltage and the current pass through zero and through their peak values at the same time. Under these circumstances, the current is said to be "in phase" with the voltage. If the circuit contains inductance and resistance only, the current lags behind the voltage; *i.e.*, it passes through its zero and peak values some time after the voltage. The current lags behind the voltage a maximum of 90 deg. when the circuit contains nothing but inductance. If the circuit contains capacity and resistance only, the current will lead the voltage and a maximum lead of 90 deg. will be reached when the circuit contains capacity only.

In a circuit containing resistance and inductance, the voltage across the resistance will be in phase with the current or lagging behind the circuit voltage. The voltage across the inductance will be 90 deg. ahead of the current. This means that this voltage will lead the circuit voltage unless the resistance in the circuit is zero, in which case the two voltages will be in phase.

In a circuit containing resistance and capacity, the voltage across the resistance will be in phase with the current or leading the circuit voltage. The voltage across the condenser will be 90 deg. behind the current. This means that this voltage will

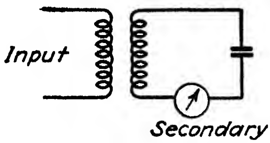


FIG. 17.—A tuned circuit.

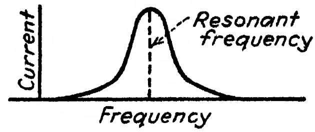


FIG. 18.—A resonance curve of a tuned circuit.

lag behind the circuit voltage unless the resistance in the circuit is zero.

Tuned Circuits.—A tuned circuit consists of a coil shunted by a condenser. Some of the characteristics of a tuned circuit can be demonstrated with the circuit shown in Fig. 17. If current of fixed voltage and varying frequency is fed into the input coil, the resulting current in the secondary will be as shown in Fig. 18.

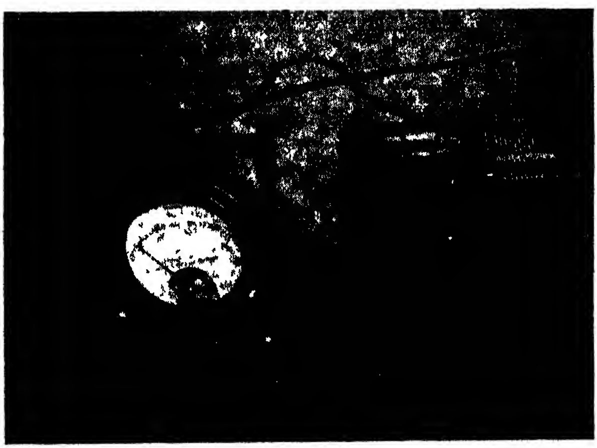


FIG. 19.—A tuned circuit. The coil and condenser are at the left. The oscillator coil is behind the meter, which indicates approximately 200 ma. of radio-frequency current.

At low frequencies, the reactance of the condenser is high, whereas, at high frequencies, the reactance of the coil is high. Therefore, at either high or low frequencies, the current is limited by these reactances. At some intermediate frequency, the two reactances cancel each other and the current is limited only by

the resistance in the circuit. The frequency at which the reactances cancel each other is known as the "resonant frequency," and the circuit is said to be tuned to that frequency. The smaller the coil, or condenser, or both, the higher will be the resonant frequency. *Two circuits are said to be in tune, or at resonance, when their inductances and capacities are such that they are resonant to the same frequency.* This does not mean that the inductances and capacities of both circuits must be the same; however, the product of the inductance and capacity in each circuit must be the same. The resonant frequency of any combination of coil and condenser can be determined from the formula

$$f = \frac{10^6}{2\pi\sqrt{LC}},$$

in which f is the frequency in cycles, L is the inductance in microhenrys, and C is the capacity in microfarads. The wave length to which any capacity and inductance will tune can be determined from the formula

$$\lambda = 1{,}885\sqrt{LC},$$

in which λ (Greek letter lambda) is the wave length and L and C are in the same units as before.

Problem: To find the wave length to which a 100-μh coil and a 0.00015-mf. condenser will tune.

In the formula $\lambda = 1{,}885\sqrt{LC}$, L will be 100 and C will be 0.00015; LC is 0.015 and $\sqrt{LC}$ is 0.1225; then $\lambda = 1{,}885 \times 0.1225$, or 231 meters approximately.

The Effect of Resistance in a Tuned Circuit.—The addition of resistance to a series-resonant circuit (most circuits used for tuning r-f amplifiers are series resonant) has two important effects: (1) The maximum value of the current at resonance will be reduced. This is easy to understand because resistance always limits current in a series circuit regardless of whether the current is direct or alternating, or audio or radio frequency. This reduction of the current causes a loss of volume in the set. To express the same thing in other words, resistance in a tuned circuit reduces the sensitivity of the set. (2) The second effect produced by the resistance is a loss of selectivity, which causes a station to spread over more space on the dial. With resistance in the circuit, the current does not drop rapidly on each side of the resonant point. This means that stations having approxi-

mately the same frequency will produce almost the same current and, therefore, nearly the same volume as the station to which the set is tuned. Briefly, resistance in a tuned circuit has two effects on a radio set: (1) It reduces the volume. (2) It reduces the selectivity of the set. For these reasons, care should be used to keep resistance out of tuned circuits. Some of the more common causes of resistance in tuned circuits are:

1. Poorly made joints.
2. Lack of pigtail connections for the rotor of the condenser.
3. Dirty spring contacts to condenser rotor.
4. Excessive amounts of poor quality of insulation used in the condenser and coil form.

Selectivity.—The selectivity of a series-resonant circuit depends on the resistance in the circuit as previously explained and also upon the ratio of the inductance and capacity in the circuit. When the inductance is large in comparison to the capacity, the selectivity is greater. This fact partly accounts for the lack of selectivity of some sets at the l-f (low-frequency) end of the band. It also accounts for the lack of selectivity on the higher frequency bands of some of the sets having two or three bands. When the h-f (high-frequency) coils are used, the capacity stays the same, but the inductance is reduced thus reducing the selectivity.

Coupling.—Coils are said to be "loose coupled" when little of the flux of one passes through the other. This occurs when the coils are separated or when they are turned at an angle to each other.

Coils are said to be "close" or "tightly coupled" when most of the flux of one coil passes through the other. This occurs when the coils are close together and have their axes in line. Loosely coupled circuits give high selectivity but low efficiency in the transfer of the signal; close coupling gives a better transfer of the signal but with reduced selectivity. The coils in i-f amplifiers are very accurately adjusted to give the proper amount of coupling for a flat-top tuning curve. This provides adequate selectivity with good quality. This subject will be discussed more completely under "Trouble Shooting."

REVIEW QUESTIONS

2-1. Name three other waves similar to radio.
2-2. What is the speed of these waves?

2-3. Give the formula for wave length.

2-4. Give the formula for finding the frequency from the wave length.

2-5. What effect does the Kennelly-Heaviside layer have on radio reception?

2-6. What is inductance?

2-7. Name four features of a coil that affect its inductance.

2-8. What is capacity?

2-9. Describe a simple condenser.

2-10. Name three features of a condenser that affect its capacity.

2-11. Define dielectric constant.

2-12. Which condensers have the least leakage?

2-13. Which condensers cannot be used on alternating current?

2-14. What type of condensers are used in power supply filters? Why?

2-15. Give the formula for condensers in parallel.

2-16. Give the formula for condensers in series.

2-17. Define reactance.

2-18. Give the formula for inductive reactance.

2-19. How does inductive reactance vary as the frequency of the current increases?

2-20. Give the formula for capacitive reactance.

2-21. How does the capacitive reactance vary as the frequency of the current increases?

2-22. Define impedance.

2-23. Give the three formulas for Z.

2-24. What is meant by the expressions "in phase" and "out of phase"?

2-25. In a ________ circuit the current lags the voltage.

2-26. In a ________ circuit the current leads the voltage.

2-27. The voltage across a condenser ________ the current through it.

2-28. The voltage across a coil always ________ the current.

2-29. In a ________ circuit the current and voltage are always in phase.

2-30. (*a*) What is the predominating reactance in a tuned circuit below resonance? (*b*) Above resonance?

2-31. Knowing the capacity and inductance in a circuit, give a formula for finding the frequency to which it will tune.

2-32. Give the formula for wave length in terms of inductance and capacity.

2-33. What effect does resistance have on a tuned circuit?

2-34. What is meant by coupling?

2-35. What is the effect of tight coupling?

2-36. What is the effect of loose coupling?

CHAPTER III

RADIO TUBES

The simplest radio vacuum tube consists of three parts enclosed in a glass or metal bulb from which as much air as possible has been pumped. The first and inside part is the filament. It consists of one or more wires which are heated to incandescence by current passing through them. The second part, consisting of a spiral spring or a very open-mesh screenlike part, is called the "grid." The third part, called the "plate," surrounds the grid. It is usually made of sheet metal, but fine-mesh screen is used in some of the smaller tubes. The base of the tube has four prongs. The two larger ones are connected to the filament. The grid and plate are each connected to one of the two smaller prongs.

The screen-grid tube has an extra grid which surrounds the plate, both inside and out. The pentode, brought out in 1930, has still another grid sometimes connected to the mid-point of the filament or to the cathode internally and sometimes connected to a separate pin on the base. Many tubes have an insulated metal tube, called the "cathode," surrounding the filament, which is heated by the filament and gives off electrons instead of the filament. When a cathode is used, the filament is called a "heater."

Operation of a Vacuum Tube.—When the proper voltage is applied across the filament terminals of a tube, the filament becomes incandescent. This condition of the filament allows large numbers of electrons to escape[1] and surround the filament like a cloud. A source of high voltage is connected between the plate and filament with the positive potential connected to the plate. The positive charge thus placed on the plate attracts the electrons surrounding the filament, and they move toward the plate. The grid is directly across the path of these electrons. In most radio circuits, the grid is maintained at a negative

[1] See Chap. I, p. 6.

potential in respect to the filament or cathode. It, therefore, has the same charge as the electrons and repels them, forcing them back toward the filament and thus reducing the number that reach the plate. Increasing the negative charge, or "grid bias," as it is called, would increase the force of repulsion and further reduce the number of electrons reaching the plate. Conversely, as the negative grid bias is reduced to zero, the plate current increases. If the grid is made positive in respect to the cathode, it will attract electrons from the cathode; however, most of them are captured by the higher positive charge on the

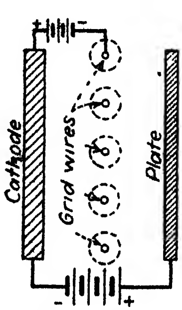


FIG 20.—Diagram illustrating the operation of a vacuum tube with low grid bias.

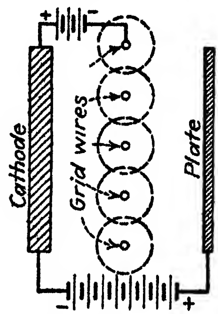


FIG 21.—Diagram illustrating the operation of a vacuum tube with high grid bias.

plate. In effect, a positive grid gives the electrons a good start on their way to the plate, at the same time retaining a few itself.

The operation of the grid is illustrated in Figs. 20 and 21. In these figures, the extent of the electrostatic field about the grid wires is indicated by the dotted circles. In Fig. 20, the grid voltage is a low negative value. This will produce a small field about the wires and leave large gaps having little if any field strength. The electrons pass easily through these gaps to the plate. In Fig. 21, the grid voltage has been increased to such an extent that the electrostatic fields surrounding the grid wires overlap and form a continuous negative field which repels all electrons trying to get to the plate. Thus, as the grid voltage is changed, the strength of the electrostatic field about it is changed, and this in turn controls the number of electrons that can reach the plate.

Fundamental Circuits of a Vacuum Tube.—There are three circuits connected with a vacuum tube that must allow direct current to flow: (1) from a source of current through the heater or filament and back to the source, (2) from the filament or cathode through the plate supply to the plate, and (3) from the filament or cathode through the grid-voltage supply to the grid. The first, or filament, circuit is known as the *A* circuit; the second, or plate, circuit is known as the *B* circuit; and the third, or grid, circuit is known as the *C* circuit. Insofar as these circuits are the basis of a large amount of the checking that is necessary in service work, the student should be sure to get an accurate and complete knowledge of them. It is a good plan to study several radio circuits, paying particular attention to these circuits. The grid circuit may be traced by starting at the control grid of the tube and tracing the wiring until the cathode or filament is reached. In this circuit, there must be no condensers because they stop direct current. The plate circuit can be traced in the same way, starting at the plate and following through until the filament circuit of the rectifier is reached. In the same manner, the circuit from the cathode should return to the center tap of the power winding on the power transformer. This winding can be identified by the fact that its ends are connected to the plates of the rectifier. In some circuits, the cathode circuit is grounded to the chassis, and, since the center tap of the power-transformer winding is also grounded, the connection is completed by the chassis.

Symbols.—The symbols E, I, and R, when applied to tube characteristics, have the same meaning as when used in Ohm's law. To avoid confusion between plate current, plate voltage, and filament or grid current or voltage, a system of subscripts has been devised. In this system, E_p stands for plate voltage, E_f for filament voltage, and E_g for grid voltage. The corresponding currents are designated by I_p, I_f, and I_g. The subscripts a, b, and c would indicate A, B, or C supply voltages or currents. E, I, and R refer to direct current or to the d-c component of pulsating-current quantities, whereas e, i, and r refer to alternating current or to the a-c component of pulsating-current quantities. Thus, E_c refers to the grid-bias voltage, whereas e_g or sometimes e_s refers to the alternating-signal voltage impressed on the grid. Similarly R_p refers to the

plate-load impedance, whereas r_p refers to the internal plate resistance.

Vacuum-tube Designations.—Originally vacuum tubes were numbered as they were developed. Many tubes of this series are still in use. Among these are the 45, 55, 75, and 80. But these designations gave no clue to the type of tube or its characteristics. Later a system was developed that gave some indication of the tubes, characteristics and construction. This system uses two numbers separated by one or two letters. The first number indicates the filament or heater voltage to the nearest volt. The last number gives the number of elements in the tube. The letters at the beginning of the alphabet are used for amplifiers and detectors. The letters at the end of the alphabet are used for rectifiers. Thus, the designation 2A3 indicates that the tube is an amplifier having a 2.5-volt filament and has three elements, obviously a plate, grid, and filament. A 25Z5 tube would be a rectifier with a 25-volt heater having five elements. These are two plates and two cathodes in addition to the filament.

At the present time, the number of tubes has increased to such an extent that the alphabet has been exhausted and double letters are being used.

The system tells neither the type of base nor whether the tube is glass or metal except in the case of glass tubes, which are otherwise similar to metal tubes. The letter G is added to the designation of these tubes.

Vacuum-tube Characteristics.[1]—Figure 22 illustrates the manner in which the plate current varies as the grid bias is changed, the plate voltage remaining constant. Several curves are illustrated to show the effect at various plate voltages. The grid bias at which the plate current becomes zero is known as the "cut-off point" of the tube.

It will be noticed that an increase in the plate voltage shifts the curve to the left without materially changing the shape. This is to be expected because the higher negative grid bias would require a higher plate voltage to overcome its opposition. Or if the cut-off points are considered, it is evident that a higher plate voltage would require a higher grid voltage to oppose it and reduce the plate current to zero.

[1] Forepart of the "RCA Tube Manual."

Figure 23 shows how the plate current varies as the plate voltage is varied, the grid bias being fixed. The several curves show the effect at different values of grid bias.

An inspection of the zero plate-current points in this set of curves also shows that a higher grid bias requires a higher plate voltage before the plate current can begin to flow. In this case,

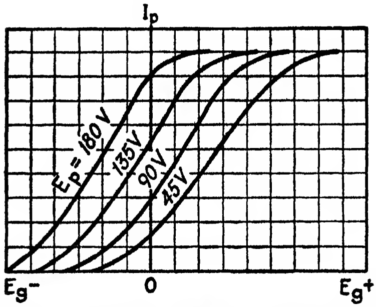


FIG. 22.—Grid-voltage vs. plate-current curves of a vacuum tube.

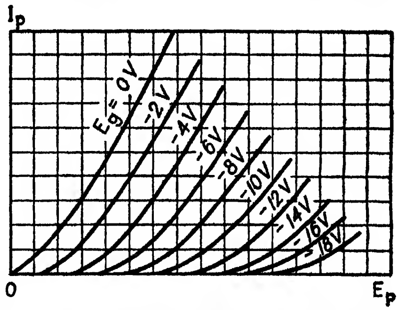


FIG. 23.—Plate-voltage vs. plate-current curves of a vacuum tube.

an increase in the grid bias moves the curve to the right without materially changing its shape.

Figure 24 shows the effect of the filament current on the plate current. Since the filament temperature depends on the filament current, the curves for filament temperature versus plate current would be practically the same. The curves in Fig. 24 bend to the right and become horizontal at a point where the filament temperature is such that more electrons are being emitted than can be attracted by the plate at the particular plate voltage being used. If the plate voltage is raised, the maximum plate current also increases, owing to the increased attraction.

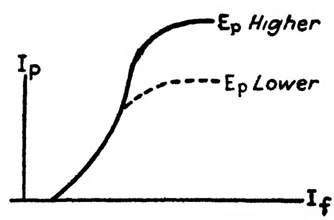


FIG. 24.—Filament-current vs. plate-current curves of a vacuum tube.

The curves in Figs. 22 to 24 show the static characteristics of a tube. This means, for instance, that E_g is varied, whereas E_p and E_f are held constant. In actual operation, these conditions do not exist because of the resistance or reactance in the plate circuit, which reduces the voltage actually on the plate as the current increases. Figure 25 shows how the E_pI_p curve varies

with changes in R_p. These curves are known as "dynamic characteristic curves." It can be seen that as R_p becomes greater the curve tends to become straighter. This decreases the distortion. However, it will also be noticed that the plate current is also greatly reduced and this reduces the amplification obtainable unless a very high-voltage power supply is used. The effect on the output can also be explained from the standpoint of Ohm's law. As R_p is increased, the *IR* drop across it increases. It will be seen then that more and more of the available plate supply is used up in the load resistance, making the plate voltage smaller as the load resistance increases. The reduced plate voltage lowers the amplification of the tube.

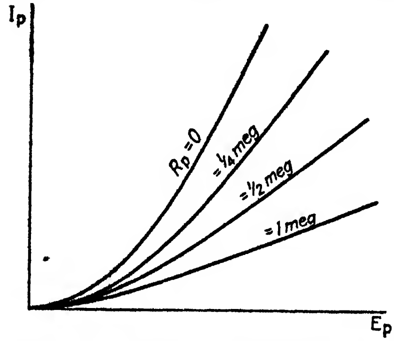


FIG. 25.—Dynamic characteristic curves.

Space Charge.—The effect produced by the cloud of electrons surrounding the filament or cathode is called a "space charge." Since it is made of electrons, it is a negative charge.

Plate Resistance.—The plate resistance r_p can be determined by dividing a small change in the plate voltage by the resulting change in the plate current. It is *not* the total plate voltage divided by the total plate current. The plate resistance varies as the plate potential or the grid bias changes. It can be determined from the E_pI_p curves of a tube, as shown in Fig. 26.

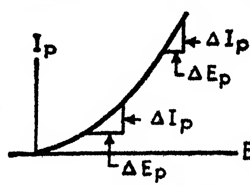


FIG. 26.—Diagram illustrating the change in the plate resistance of a vacuum tube when operated at different parts of its characteristic curve.

The symbol Δ (Greek letter delta) is used to indicate a very small increase or decrease in the quantity with which it is used. From Fig. 26, $r_p = \frac{\Delta E_p}{\Delta I_p}$, it can be seen that r_p increases as the voltage on the plate is reduced because ΔE_p becomes relatively larger than ΔI_p as the voltage is reduced.

Amplification Factor.—The amplification factor μ of a tube tells how many times the signal voltage may be increased by

passing through the tube. It can be determined by dividing a small increase in the plate voltage by the change in the grid voltage that is necessary to bring the plate current back to its original value. Thus $\mu = \frac{\Delta E_p}{\Delta E_g}$, maintaining I_p constant. The amplification factor increases as the grid bias decreases. It increases as the plate and screen-grid voltage increase.

Mutual Conductance or Transconductance.—The mutual conductance *gm* of a tube can be found by dividing a small change in the plate current by the change in the grid voltage that caused the change, all other voltages remaining constant. It can also be found by dividing the amplification constant by the plate resistance. The mutual conductance is not a fixed quantity but varies as the plate resistance changes.

Conversion Conductance.—Conversion conductance is defined as the ratio of the i-f component of the mixer output current to the r-f signal voltage applied to the grid. This characteristic gives the ratio of the i-f output voltage to the r-f input voltage of the first detector-oscillator tube or tubes in a superheterodyne receiver. High conversion conductance would indicate that a high i-f voltage could be obtained from a relatively low signal input.

Power Sensitivity.—The power sensitivity is found by dividing the watts output by the square of the signal voltage impressed on the grid-cathode circuit.

Theory of Power-detector Action.—The power detector must have its grid negatively biased so that the action takes place at the bend of the characteristic curve, as shown at *A* in Fig. 27. The bias places a steady voltage across the grid and cathode. The incoming signal also puts a voltage across the grid and cathode, but this voltage is alternating. During one half cycle, it adds to the bias voltage, whereas during the next half cycle, it subtracts from the bias voltage. The actual effective voltage on the grid, therefore, rises and falls during the signal voltage cycle. In Fig. 27, the curve *B* indicates the alternating signal voltage, and *F* indicates the bias voltage. The distance between the curve *B* at any point and the zero grid-voltage line represents the actual grid voltage at that time. Note that the actual grid voltage is varying according to the signal influctuations. But changing the grid bias changes the plate current. The resulting

changes in the plate current are shown at *C*. The important thing to notice is that the plate current increases more than it decreases from its normal steady value *D* owing to the grid bias *F*. The result is a current through the phones, which has the same effect on the diaphragm as a direct current, as shown at *E*.

This current will move the diaphragm whereas the h-f current would not because the diaphragm cannot vibrate as fast as the current alternates. A detector acts as a rectifier to a certain extent.

The theoretical explanation of the action of a grid-condenser grid-leak detector is too complicated to present at this time. However, a few notes on its practical application will be given.

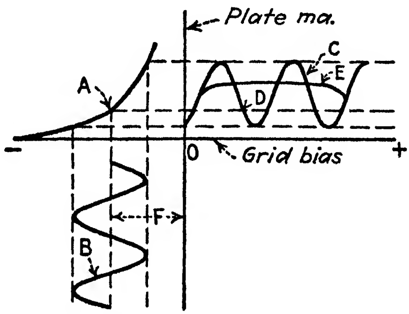


Fig. 27.—Diagram illustrating detector action.

A high-resistance (5 to 10 megohms) grid leak will not only make the detector more sensitive to weak signals but also will not allow a strong signal to leak back to the filament. Therefore, the signals pile up on the grid and block the operation of the tube. The size of the grid condenser is also important. The best size for broadcast wave lengths is 0.00025 mf. For short waves, a 0.00001-mf. grid condenser is often used. Many of the older condensers are so leaky that the signal can leak off through them and, therefore, a grid leak is not necessary.

Theory of Amplifier Action.—The main difference in the operation of a tube as an amplifier rather than as a power detector is the amount of *C* bias used. For undistorted amplifier operation, the bias on the grid must be such that the action takes place on the straight portion of the characteristic curve, as shown in Fig. 28. Since the steepness of the curve is the same on both sides of the *C* bias point that has been selected, the plate cur-

rent will decrease as much as it increases, and no more, as the signal voltage swings the grid bias up and down. The plate-current curve then will be an exact reproduction of the applied signal-voltage curve. The negative bias must be higher than the peak voltage of the signal; otherwise, the grid will become positive during that portion of the cycle when the signal voltage is positive and exceeds the *C* bias. This would allow the grid to attract some of the electrons that should go to the plate, and distortion would result.

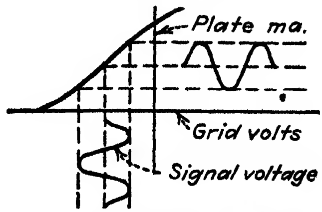


FIG. 28.—Diagram illustrating amplifier action.

Tetrode or Screen-grid Tubes.—The 1T4, 1D5GT, 6SK7, 1851 24A, 32, and 36 type tubes belong to this group.

The amplification factor of a triode, or three-element tube, is limited usually in design to a low value, because of the possibility of feedback from the plate circuit to the grid circuit through the capacity existing between the elements of the tube. To overcome this difficulty, a screen grid is placed between the control grid and the plate, which is so connected in the circuit that it shields the control grid from the feedback coming from the plate circuit.

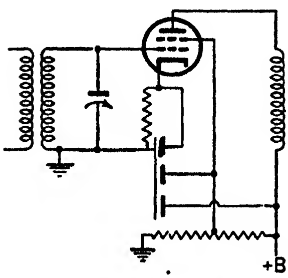


FIG. 29.—Circuit diagram of a screen-grid radio-frequency amplifier.

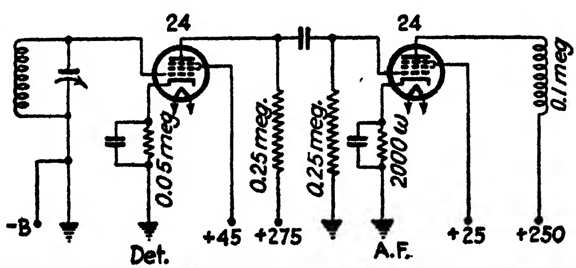


FIG. 30.—Circuit diagram of screen-grid tubes used as a detector and audio amplifier.

With this arrangement, the amplification factor can be raised many times its former limit. Figure 29 shows the circuit of

this tube when used as a r-f amplifier. In Fig. 30 it is used as a detector and as an a-f amplifier.

The screen-grid voltage is best obtained from a voltage divider inserted across the plate supply.

Power Amplifier Pentodes.—This group includes 33, 38, 41, 42, 43, 47, 2A5, 6G6G, 6K6G, 6F6, and 25A6 tubes.

The addition of the screen grid to the radio tube made a higher amplification possible, but it was found that the power output of the tetrodes was limited for the following reasons: If the plate current of a screen-grid tube is increased to obtain more power output, the increased number of electrons striking the plate at high velocity knock some of the electrons out of the surface atoms and these are attracted by the positive charge on the screen grid. The phenomenon of electrons leaving the plate in this manner is known as "secondary emission." This emission causes serious distortion and can be eliminated in tetrodes only by reducing the plate current.

Fig. 31.—These are grids from a vacuum-tube model. The one on the left is a sharp cut-off grid. The one on the right is a supercontrol grid.

To overcome this difficulty, a fifth element—called the "pentode grid" or "suppressor grid"—is inserted between the screen grid and the plate and connected to the cathode. Its connection to the cathode gives it a negative charge, which enables it to repel the electrons knocked out of the plate and to throw them back into the plate.

Supercontrol Radio-frequency Screen-grid Tubes.—This group includes the 34, 39/44, 1A4, 6D6, 6K7, and 78 type tubes, which are also known as "variable μ tubes."

These tubes differ from the regular screen-grid tube in their control-grid structure. Instead of having uniform spacing of the grid wires, the end turns are closely spaced whereas the middle turns are widely spaced. With weak signals and low grid bias, due to volume control setting, the end turns of the grid are active.

With heavy signals and high grid bias, the electron flow from the portion of the cathode covered by the ends of the grid structure is blocked and the central portion is active. Fine spacing of the grid wires gives a higher amplification factor than the coarse spacing. The supercontrol screen-grid tube then gives high amplification on weak signals and low amplification on strong signals.

Pentodes Used as Audio-frequency Voltage Amplifiers.—Figure 32 illustrates the use of 57, 6C6, and 6J7 tubes as a-f voltage amplifiers. The voltage amplification in this circuit, exclusive of the transformer, is 100. This type of circuit is often used as the preamplifier for a ribbon microphone.

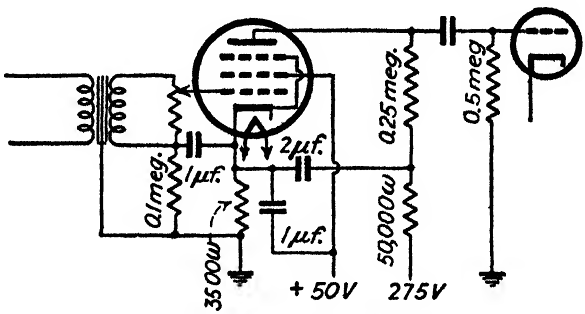


Fig. 32.—Circuit diagram of a pentode used as an audio amplifier.

Mercury-vapor Rectifying Tubes.—These tubes are full-wave rectifiers. Instead of a vacuum, they contain mercury vapor, which supplies the extra electrons needed for high output.

It is characteristic of mercury-vapor rectifiers that no appreciable plate current will flow until the plate voltage reaches a certain critical positive value. At this value the attraction of the plate for the electrons increases their velocity to such an extent that, when they collide with one of the mercury atoms, they blast some of the electrons out of it. These new electrons are immediately attracted to the plate so that by the time the original electrons reach the plate they are accompanied by a far greater number of electrons obtained from the mercury atoms. This sudden rush of current, each time either plate reaches the critical positive value, may set circuits in the vicinity into oscillation. This results in a noisy receiving set. To overcome this difficulty, small r-f chokes are placed in the plate

circuits of the rectifier. This precaution is usually not necessary when a-f amplification only is present.

After the electron collision has removed one or more electrons from the mercury atoms, the remaining ion is positively charged and is attracted to the negative filament. When the filament temperature is such that an excess of electrons is being emitted, the filament will be surrounded by a cloud of electrons. When the ions reach this cloud, they immediately acquire one or more of the electrons and so become neutral electrically. But if the filament emission is low owing to low filament voltage, the ions will bombard the filament with such force that they knock the filament coating off and ruin the tube.

These tubes require good ventilation, for if they become overheated the ionization increases to such a point that the current can flow in both directions through it.

Pentode Output Tubes.—These tubes are very critical as to plate load for minimum distortion. For best results, the load should be, in effect, a resistor. This result is approximated by using a circuit consisting of a condenser and resistance in series across the primary of the output transformer. Sometimes two or three of these circuits with different values of resistance and capacity are used.

Beam-power Output Tubes.—These tubes have a very high power sensitivity. In this respect they resemble the pentode type of power tube. They do not have an actual suppressor grid; however, owing to the construction features of the tube a virtual cathode is formed at the point where a suppressor grid would be located.[1] To obtain this virtual cathode it was necessary to confine the electrons passing from the cathode to the plate in a beam. This was accomplished by using an oval-shaped cathode, control grid, and screen grid with the wire on both grids wound spirally with the same pitch and in line with each other; *i.e.*, looking from the cathode, the screen-grid wires are directly behind the control-grid wires. At each end of these ovals, a metal plate connected to the cathode is placed which repels any electrons that are emitted by the portion of the cathode near them. Thus the electrons are confined to two beams issuing from the flatter portions of the cathode.

[1] A virtual cathode is a space having the same voltage characteristics as a real cathode.

For minimum distortion with a single 6L6, it is important that the grid bias and the plate resistor of the preceding tube be maintained at the original values. Any change in these values will introduce noticeable distortion.

The 6L6 can be used singly or in push-pull Class A, AB, or B. Of course, if operation under these classes is successful, the proper input and output transformers must be used and a suitable power supply be provided.

Mixer Tubes.—Though these tubes are used most often as a mixer tube, in superheterodynes they have other very convenient uses. These include operation as an i-f amplifier and as an audio amplifier in a volume-expander circuit. The latter application will be explained in detail in connection with audio amplifiers. The 6L7, an all-metal tube, has a heater, a cathode, five grids, and a plate. One grid is connected to the cathode internally and is used as a suppressor, and two of the grids are tied together and shield the control grid connected to No. 5 pin. The remaining grid is connected to the cap and is a second control grid. When this tube is used as a mixer, the grid connected to the top cap is used for the r-f input. The other control grid is connected to the grid end of the oscillator-tuned circuit, which uses another tube. By this arrangement, the advantages of electron-coupled oscillator circuits are obtained, and increased oscillator stability is achieved by the use of a separate oscillator tube.

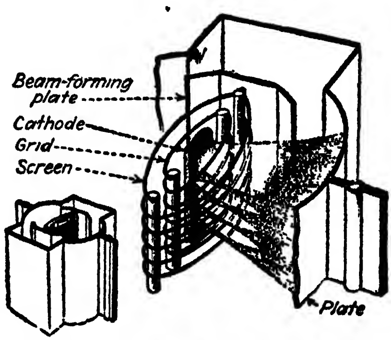


FIG. 33.—Internal structure of a beam power tube. (*Courtesy of RCA Manufacturing Company, Inc.*)

When this tube is used as an i-f amplifier, both grids may be connected to the a.v.c. system, which provides very satisfactory operation with only a single-controlled tube.

Electron Tuning Indicator Tubes.—These tubes are used primarily as tuning indicators. The schematic diagram is shown in Fig. 34. They consist of a heater, cathode, grid, and plate similar to a triode. In addition, they have a ray-control elec-

trode connected to the plate and a target that has its own contact prong on the base. The target is covered with a substance that becomes fluorescent when bombarded by electrons. The target is connected directly to $B+$ and the plate is connected to the same voltage through a 0.25- to 1-megohm resistance. The grid is connected to the a.v.c. system often through a voltage divider, for the maximum grid voltage is 8 volts for the 6E5. As a signal is tuned in, the a.v.c. voltage increases and this increases the grid bias on the 6E5, which decreases the plate current. This reduces the drop in the plate resistor and increases the potential of the plate and the ray-control electrode connected to it. The plate, which is now less negative in respect to the target, allows the electrons to reach a greater area on the target, which reduces the dark area to a thin line.

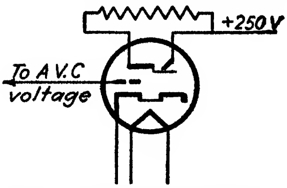


FIG. 34.—Circuit diagram of a tuning indicator tube.

The 6U5/6G5 tube is similar to the 6E5 except that it has a variable-mu grid, which enables it to handle the entire a.v.c. voltage, thus eliminating the necessity of a voltage divider.

REVIEW QUESTIONS

3-1. Describe the construction of a triode.
3-2. What is the purpose or function of the cathode?
3-3. What is the purpose of the plate?
3-4. What is the purpose of the grid?
3-5. Show by diagram or otherwise the three fundamental circuits of a vacuum tube.
3-6. What is meant by "cut-off"?
3-7. What effect will low E_f have on I_p?
3-8. What effect does a high resistance in the plate circuit of a tube have on the E_gI_p curves?
3-9. Wh t is meant by the expression "space charge"?
3-10. Define plate resistance.
3-11. How can the plate resistance of a tube be varied?
3-12. Define amplification factor.
3-13. How does it vary with the grid-bias, plate, and screen-grid voltages?
3-14. Define transconductance.
3-15. Define power sensitivity.
3-16. Describe power-detector action.
3-17. Describe amplifier action.
3-18. What is the purpose of the screen grid?
3-19. What is the purpose of the pentode grid?

3-20. What is the usual potential of the screen grid?

3-21. What is the usual potential of the pentode grid?

3-22. What is the difference in the construction and operation of a regular and a super control grid?

3-23. What is the effect of low filament voltage on mercury-vapor rectifiers?

3-24. What is a virtual cathode?

3-25. Show a circuit diagram of an electron tuning indicator.

CHAPTER IV

TEST EQUIPMENT

The purpose of this chapter is to discuss test equipment, what can and what cannot be done with it, the advantages and disadvantages of specific pieces of equipment, but not to present at this time definite instructions on the use of the equipment. This phase of servicing will be covered more thoroughly in a subsequent chapter. This chapter should help you to select test equipment wisely, to be able to judge the relative merits of two similar pieces of equipment, and also to keep you from making false conclusions from readings taken with certain kinds of test equipment.

Radio test equipment may be divided into two groups: In one group a single instrument movement is used for many purposes. In the other group each function is accomplished with a separate instrument movement. The first group has the advantage of greater portability and lower cost. The second group has the decided advantage that when the movement in one piece of equipment is damaged all the other pieces can be used to pinch-hit for the one out of order. It would seem to be the wise thing for the serviceman who is just getting started to buy one of the volt-ohm-milliammeter combinations with a single instrument movement and then add separate voltmeters, ohmmeters, and milliammeters at a later date. But the final decision must be made on the basis of funds available, the amount of servicing being done, and to some extent on the methods used.

Meters.—If the readings are to be of any assistance in locating the difficulty, they must be dependable. This requires that the meters be accurate within 2 per cent. They must also be of rugged construction in order to maintain this accuracy. In addition to these qualifications, the meters should create the least possible disturbance in the circuits to which they are connected. This means that the current necessary to operate the meter must be a minimum. The two desirable features, *viz.*,

ruggedness and low operating current, are antagonistic, and a compromise must be made. For this reason, an 0–1 ma. movement is usually chosen. There are several instruments on the market that use 20- or 50-μa movements. However, these should be handled very carefully or the bearings will be damaged. This difficulty coupled with the fact that even the small current that they require does interfere with the operation of many circuits makes it advisable to use a 0–1 movement for instruments and use a vacuum-tube voltmeter if the current drawn by an instrument would interfere with the operation of the circuit.

Meter Scales.—A careful check of all the voltages and currents recommended for the tubes of one of the large manufacturers shows that the following scales will best meet the needs of the serviceman: For d-c voltages, 0–15, 0–150, 0–300, 0–600, 0–1500, 0–3,000; for a-c voltages, 0–10, 0–150, 0–1,000, 0–5,000; for d-c milliamperes, 0–1, 0–10, 0–60, 0–600. In using the meters, it is good practice to use the largest scale on which an accurate reading can be obtained, because by so doing a minimum amount of current is used and the least amount of change of voltage is caused by the current passing through the meter. However, since the accuracy is 2 per cent of the full scale reading, greater accuracy so far as the meter is concerned is obtained by using the smallest scale possible. These two factors in the accuracy of the reading are therefore antagonistic to each other.

Tube-prong Numbering.—In the following discussion, the bottom view of the socket is considered at all times. The filament or heater prongs on all nonoctal-base tubes are larger than the other prongs. The prongs on the octal-base tubes are all the same size. In the octal-base tubes none of the prongs are set aside for any particular purpose. In each model the elements of the tube are connected to the pins that give the best results for that particular type of tube.

The octal-base tubes all use the same socket. It can take up to eight pins. The tube bases have six, seven, or eight pins, which are all arranged on the same size circle. The six- and seven-pin bases simply omit two or one of the eight pins. The rest are left in the same positions. In the center of the base is a longer insulated pin provided with a key that prevents incorrect placement of the tube in the socket. The pin numbering is shown in Fig. 35.

The Loktal-type tubes have no base. The contact pins are sealed in the glass bottom. The lower portion of the tube is covered with a metal shield with a guide pin and key similar to the octal-base tube. There is a groove around the bottom of the guide pin which fits into a catch on the socket. This provides a lock-in feature. It is difficult to remove these tubes by a straight upward pull. The socket lock is released with a slight offside pressure, and then the tube can be easily removed.

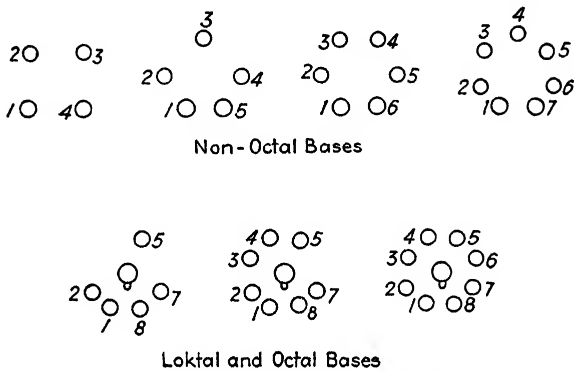


Fig. 35.—Tube-prong numbering system.

Color Coding. *Resistors.*—The Radio Manufacturers Association has standardized on the following color coding for resistance-value identification:

Color	Code	Color	Code
Black	0	Green	5
Brown	1	Blue	6
Red	2	Violet	7
Orange	3	Gray	8
Yellow	4	White	9

The body color gives the first figure in the resistance value; the end color gives the second figure; and the dot indicates how many zeros are to be added to the two figures already obtained. When there seems to be no end color or dot, it means that the end color or dot is the same as the body color. For example: An all-red resistor would be 2,200 ohms. The red body gives the first 2, the red end the second 2, and the red dot indicates two zeros.

For certain applications of resistors where it is essential that the value be very near the indicated amount, the tolerance is indicated by coding the resistor for a value which is either the

largest or smallest value that can be used. For example: If a resistor had to be within 5 per cent of 200,000 ohms, it would be coded for 190,000 or 210,000 ohms.

In 1940 a second method of color coding resistors was introduced. Three color bands are placed near one end of the resistor. Beginning at the end, the first color gives the first figure; the second band gives the second figure; the third band indicates the number of zeros to add to the first two figures. If there is no fourth band, the accuracy of the resistor is 20 per cent. A *silver* band indicates 10 per cent accuracy and a gold band 5 per cent accuracy.

Condensers.—Condensers are color coded by three dots. When the trade name or trademark is right side up, the dot on the left indicates the first figure. The middle dot indicates the second figure. The right-hand dot indicates the number of zeros to be added to the first two figures. The capacity is then indicated in micromicrofarads.

Color Code for Voltage Rating of Tubular Condensers.—Voltage rating is shown by the color of the band.

Color	Volts
Red	200
Yellow	400
Blue	600
Gold	1,000
Bronze	1,600
Silver	2,000

Audio Transformers.—The following color code is recommended by the R.M.A. for interstage and output transformers:

Color	
Red	*B*+
Green	1st grid or high side of voice coil
Black	−C or low side of voice coil
Green	2d grid
Blue	Plate

When the polarity of the coils must be indicated, the inside (start) of the primary is brown and the inside (start) of the secondary is yellow. For output transformers, the inside (start) of the secondary is black.

Power Transformers.—The following code colors are used for power transformers:

Color	
Black	Primary leads
Black	Common of tapped primary
Black and yellow	$\frac{50}{50}$ stripes. Tap of primary
Black and red	$\frac{50}{50}$ stripes. Finish of primary
Red	Plate leads of high-voltage secondary
Red and yellow	$\frac{50}{50}$ strips. High-voltage center tap
Yellow	Rectifier filament leads
Yellow and blue	$\frac{50}{50}$ stripes. Rectifier center tap
Green	Filament winding 1
Green and yellow	$\frac{50}{50}$ stripes. Filament 1 center tap
Brown	Filament winding 2
Brown and yellow	$\frac{50}{50}$ stripes. Filament 2 center tap
Slate	Filament winding 3
Slate and yellow	$\frac{50}{50}$ stripes. Filament 3 center tap

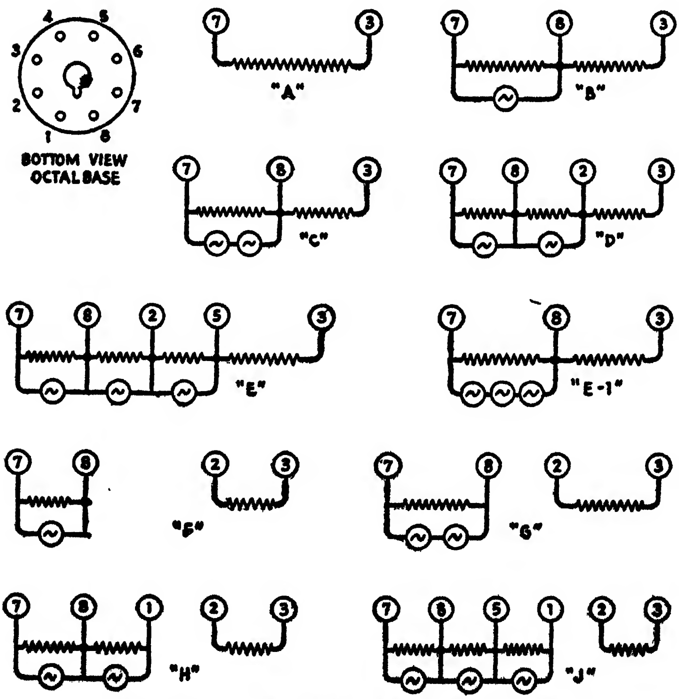


Fig. 36.—Internal connections of ballast tubes.

Pilot Lamps and Dial Lamps

Bead color	Volts	Amp.	Base	Fig. No.	Normal candle power	Bulb	Usual service	Mazda No.	Raytheon No.	Sylvania No.	RCA part No.
Brown	6–8	0.15	Screw	1	0.5	Clear	Radio dials	40	40	S40	4340
Brown	6–8	0.15	Bay	5	—	—	—	47	40A	S47	31480
White	2.5	0.50	Screw	1	0.5	Clear	Radio dials	41	41	S41	2755
Green	3.2	0.50	Screw	1	—	—	—	—	42	—	—
White	2.5	0.50	Bay	5	—	—	Dials and tuning meters	—	43	S43	—
Blue	6–8	0.25	Bay	5	0.75	Clear	Dials and tuning meters	44	44	S44	11891
Green	3.2	0.50	Bay	5	—	—	—	—	45	—	—
Blue	6.8	0.25	Screw	1	0.75	Frosted	Dials and tuning meters	46	46	S46	5226
Pink	2.0	0.06	Screw	1	—	—	Battery set dials	—	48	S48	4348
Pink	2.0	0.06	Bay	5	—	—	—	—	49	—	43101
White	2.1	0.12	Bay	5	—	—	Battery set dials	—	49A	S49	—
White	6–8	0.20	Screw	2	1.0	Clear	Auto sets and flashlights	50	50	—	4991
White	6–8	0.20	Bay	4	1.0	—	Auto sets and auto panels	51	51	S51	11765
White	6–8	0.40	Bay	3	1.5	Clear	Auto sets and parking lights	55	55	S55	5117
White	2.9	0.17	Screw	1	—	—	Radio dials	—	292	S292	—
White	2.9	0.17	Bay	5	—	—	Radio dials	—	292A	S292A	—
—	12–16	0.10	Bay	2	—	Clear	—	53	—	—	13952
—	12–16	0.2	Bay	3	1.5	Clear	—	57	—	—	30691
—	6–8	0.54	Bay	—	3.0	—	—	63	—	—	13186
—	120	0.08	Screw	—	—	—	—	—	—	—	10438
Green	3.2	0.35	Screw	1	—	—	Radio dials	—	—	S42	—
White	3.2	0.35	Bay	5	—	—	Radio dials	—	—	S45	—
Brown	18.0	0.25	Screw	—	—	—	Coin machines	—	—	S1455	—
Brown	18.0	0.25	Bay	—	—	—	Coin machines	—	—	S1455A	—
—	130	—	Screw	—	—	Clear	—	—	—	—	18981
—	120	0.05	Screw	—	—	Clear	—	—	—	—	23216
—	118	0.06	Screw	—	—	—	—	—	—	—	36728

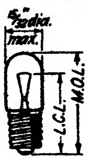


Fig. 1.

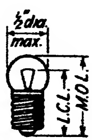


Fig. 2.

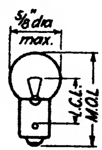


Fig. 3.

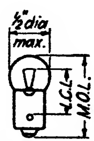


Fig. 4.

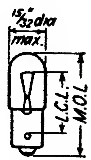


Fig. 5.

Ballast Tube R.M.A. Numbering.—The internal connections and voltage characteristics of ballast tubes used in a-c d-c receivers are indicated by the type number and its arrangement. As an example of the R.M.A. coding, note type BK-36-C.

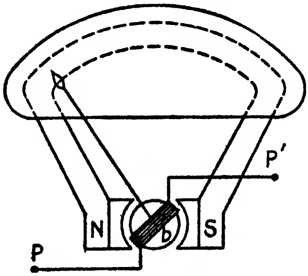


FIG. 37.—Diagram of a D'Arsonval movement.

The initial letter B indicates that provision is made for one or more pilot lights. The second letter indicates the type of pilot light used. K indicates that the light draws 150 ma.; L in this position would indicate that the lamp took 250 ma.; and M would indicate a 200-ma. light. The figures in the center indicate the total voltage drop across the entire ballast, including the pilot light if one is used. The final letter indicates the circuit of the ballast as indicated in the diagrams shown in Fig. 36.

Shunts and Multipliers for Instruments.—Before discussing the subject of set analyzers any further, the subject of shunts and multipliers for instruments should be considered. The word "instruments" is used to designate all indicating voltmeters, ammeters, and wattmeters. The term "meter" is used only for integrating devices, such as watt-hour meters. First, the general principles upon which voltmeters and ammeters are constructed will be discussed. The movement in either a voltmeter or an ammeter is fundamentally the same. All instruments with sufficient accuracy for test work on d-c circuits have a D'Arsonval movement.

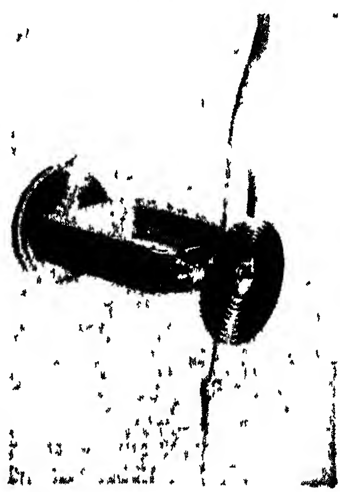


FIG. 38.—Moving coil, hair springs, and a portion of the pointer of a D'Arsonval movement. (*Photograph by Nick Brauner.*)

Figure 37 shows diagrammatically the construction of this movement. It consists of a permanent magnet that supplies a fixed magnetic flux. The current to be measured passes through

the rectangular coil *B*, which is suspended in the flux. The current is led into this coil by a spiral hairspring at the top and is led out by a similar spring at the bottom. These springs are also used to bring the pointer back to the zero position. They are

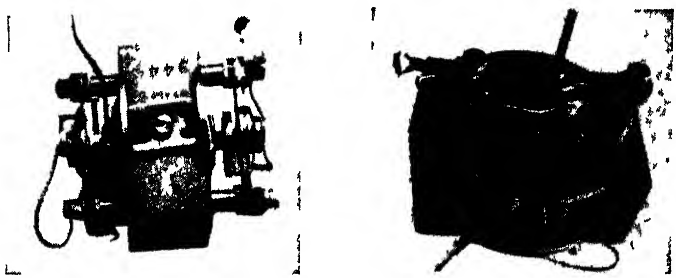


Fig 39.—Moving coil installed in pole pieces (*Photographs by Nick Brauner.*)

shown in Figs 38 to 41. When current is passed through this coil in the proper direction, the upper side of it (see Fig. 37) becomes a north pole and the lower side a south pole. The attraction between these poles and the poles of the permanent

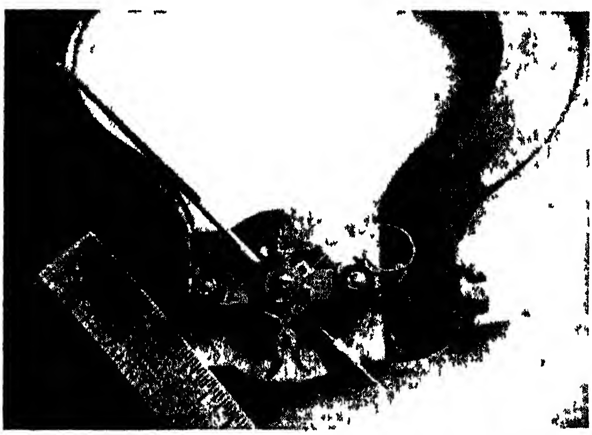


Fig. 40.—Pole pieces set in place in permanent magnet. (*Photograph by Nick Brauner.*)

magnet causes the coil to rotate clockwise, moving the pointer over the scale. The greater the current through the coil, the greater the magnetism will be and, therefore, the greater the movement of the coil against the tension of the springs. Other

views of D'Arsonval movement are shown in Figs. 39 and 40. This movement is used for ammeters, milliammeters, and volt-

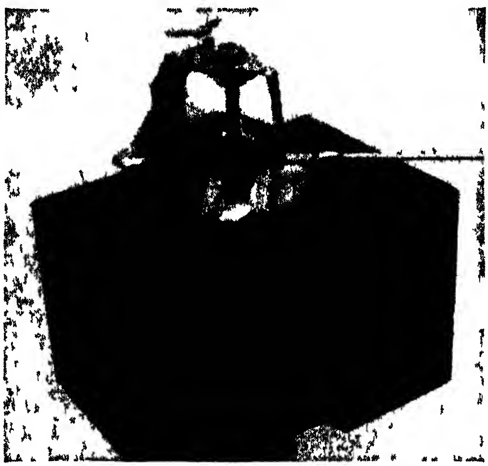


Fig 41.—Model of D'Arsonval movement

meters. The circuit of a voltmeter is shown in Fig. 42. If a 0- to 15-volt scale is desired, the necessary resistance is found by dividing the full-scale voltage desired by the current taken by the movement at full scale and then subtracting the resistance of the movement if extreme accuracy is required. In most cases, this will be so small compared with the series resistor that it can be neglected. If more than one scale is desired, the circuit shown in Fig. 43 is used. Notice that the total resistance between the negative terminal and the instrument is always the voltage at that terminal divided by the current

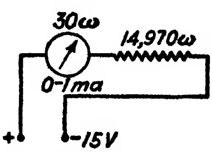


Fig 42.—Circuit diagram of a single-scale voltmeter.

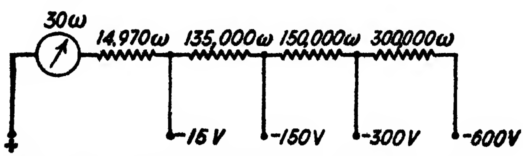


Fig. 43.—Circuit diagram of a multiscale voltmeter.

taken by the movement at full-scale reading. The accuracy of a voltmeter depends on the accuracy of the resistors that are used

in it. Carbon resistors are not suitable for two reasons: (1) They are accurate only within 10 per cent when new. (2) Even if they are accurate when the instrument is constructed, they will not remain so because these resistors change in value with age.

A word of caution is in order at this point. All instruments do not use a 0–1 ma. movement; in fact, some types use as high as 30 or 40 ma. at full scale. It is impossible to make a satisfactory radio-testing instrument with any movement that uses more

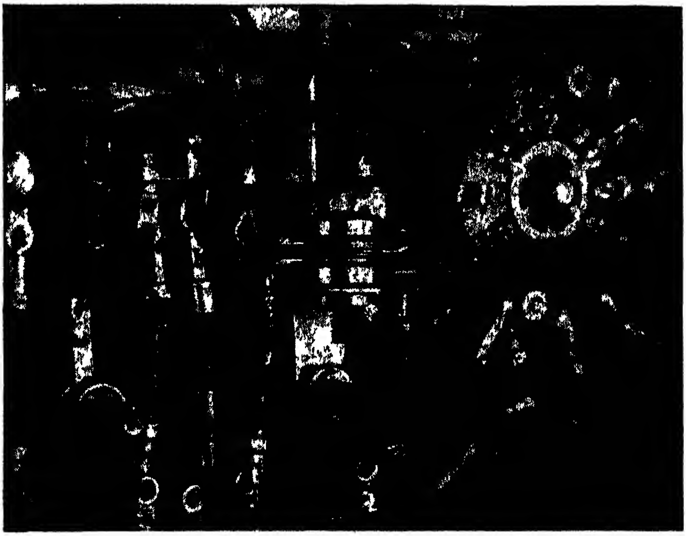


Fig. 44.—A portion of the back of the panel of a volt-ohm milliammeter. The pencil point is against the copper oxide rectifier.

than 1 ma. at full scale. In stating that characteristic of an instrument, the expression "ohms per volt" is used. The instruments discussed in the preceding description of analyzers are all 1,000 ohms per volt. This result is obtained by dividing the total resistance in the circuit by the full-scale voltage.

The D'Arsonval-instrument movement will not work on alternating current, because if alternating current is passed through the moving coil, the magnetism in it is reversed every half cycle, and this reverses the direction of the movement of the pointer. Since reversals occur very rapidly, the needle does not have time to get started in either direction and so it merely

vibrates rapidly at the zero position even when sufficient current is passed through it to cause it to burn out. However, this movement is used to measure alternating current and voltage by connecting a very small copper oxide rectifier between the current to be measured and the meter. The rectifier changes the alternating current to direct, which is then measured by the meter in the usual manner. By this method, the meter is accurate for only one frequency and this frequency must be below about 200 cycles.

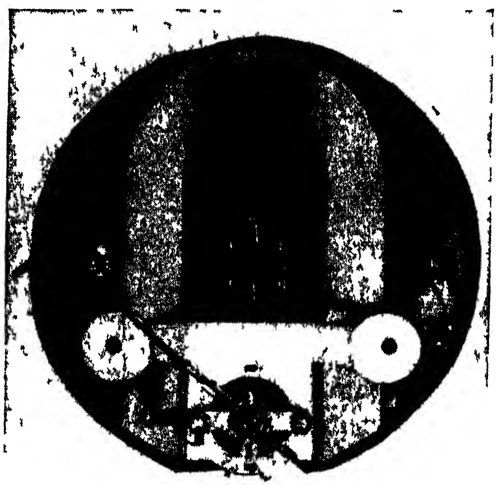


FIG 45—A thermocouple instrument with the scale removed The thermocouple is connected to the two resistance wires shown in the center between heavy copper terminal strips The D'Arsonval movement is in the lower center

A second method is used to measure alternating current of any frequency. It requires a thermocouple connected across the movement. The thermocouple is heated by a piece of resistance wire connected in series with the circuit in which the current is to be measured. Since an a-c ampere is defined as the amount of alternating current that will have the same heating effect as 1 amp. of direct current, this meter will be accurate for direct or alternating current of any frequency whether it be 60 cycles, any of the audio frequencies, or even any of the radio frequencies including frequencies well over a million cycles per second. This meter is slightly slow in recording the proper amount owing

to the fact that it takes an appreciable amount of time for wire to heat up and, therefore, effect the thermocouple. For this reason, care should be exercised when using this meter to see that excessive current is not allowed to flow through the meter, because the resistance wire has very little overload capacity and will burn out very quickly if only a slight amount of excessive current is allowed to pass through.

A hot-wire ammeter can also be used to measure alternating current. A diagram of a simple type of this meter is shown in Fig. 46.

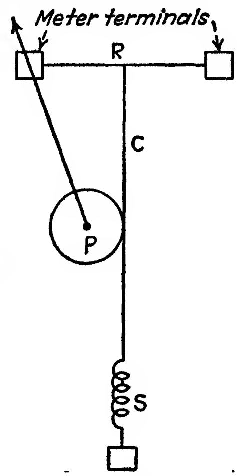


FIG. 46.—Diagram of a hot-wire ammeter.

The current to be measured passes through the resistance wire R. The heat produced causes this wire to expand. The flexible wire C, which is in some meters a very fine chain, is connected to the center of this wire and then wrapped once or twice around the pulley P and is held taut by the coil spring S. As the resistance wire expands, the spring takes up the slack in the chain and in so doing revolves the pulley and, therefore, moves the pointer over the scale.

This type of meter is also suitable for all types of current because the heating effect would be the same for any type of current. One disadvantage of the meter is that the zero current position of the pointer changes as the room temperature changes, and this necessitates setting the pointer at zero before any measurement is made.

The electrodynamometer type of instrument is also suitable for alternating or direct current. The circuit of this type of meter is shown in Fig. 48.

The principle of the meter is the same as that of a D'Arsonval movement, the difference being that the permanent magnet in the D'Arsonval is replaced by electromagnets in which no iron is used.

When the current is passed through the meter in one direction, the polarity of the various coils will be as indicated on the diagram. If the current is reversed, the polarity of all the coils will be reversed but the turning effect on the center coil will be exactly the same as it was before the current was reversed.

This meter, therefore, can be used either on direct current without any regard for the polarity or on an alternating current. For alternating current, it is limited to frequencies below about 200 cycles because at higher frequencies the impedance of the

FIG 47 —A dynamometer movement One stationary and one moving coil can be clearly seen A portion of the top of the rear stationary coil can also be seen The frame is aluminum alloy

meter is sufficiently high so that sufficient current cannot get through the instrument to cause a deflection. It will be accurate only at the frequency at which it is calibrated. This is due to

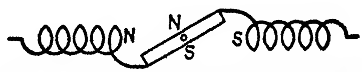


FIG. 48 —Diagram of an electrodynamometer movement.

the fact that the impedance of the instrument varies with the frequency.

The characteristics of the various types of instruments are shown in tabular form below.

TYPE	USES
D'Arsonval movement	For direct current only
D'Arsonval movement with copper oxide rectifier...	For alternating current at 1,000 ohms per volt or more. Can be used as output meter. Calibration changes with frequency
D'Arsonval movement with thermocouple	For alternating current or direct current. Accurate for all frequencies except the ultra high
Hot wire..............................	For alternating current or direct current. Accurate for all frequencies except the ultra high
Electrodynamometer....................	For direct current or alternating current below 200 cycles. Accurate only at the frequency at which it is calibrated

Alternating-current instruments as a rule use more current than the d-c instruments; but since they are used in lower impedance circuits, this is not so detrimental as it would be in a d-c instrument. The value of the resistors for use with a-c instruments is determined in the same manner as for d-c instruments. However, the resistors used must be noninductive or the accuracy of the instrument will be very low unless calibrated and used on a fixed frequency. Thermocouple- and rectifier-type a-c voltmeters with a sensitivity of 1,000 ohms per volt are on the market. These instruments are much less rugged than the ordinary type of a-c instrument.

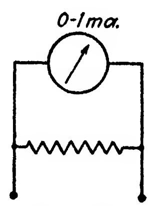


FIG. 49.—Circuit diagram of a simple instrument shunt.

The fundamental circuit for ammeters and milliammeters is shown in Fig. 49. To obtain any current reading at full scale, the resistor across the movement is adjusted so that all the current with the exception of 1 ma. flows through the resistor and the 1 ma. flows through the movement. The value of the resistor can be found by using the principles of shunt circuits. If two resistors are in parallel, the resistor having the less resistance will carry the larger current. Thus, if one resistor were twice the other, it would carry only half the current of the other. If a 0–10 ma. scale is desired, the resistor must carry 9 ma. and the movement, 1 ma. The resistor, then, carries nine times the

current of the movement, and so its value will be $\frac{1}{9}$ the resistance of the movement. If the movement has 30 ohms resistance, the resistor will be $\frac{30}{9}$ or $3\frac{1}{3}$ ohms. Since most of the shunt resistor values are very small, the amount of solder used to connect them in the circuit will alter the resistance materially. For this reason, their value should be computed roughly and then the correct value obtained by adjusting the amount of solder allowed to come in contact with the wire. Because of the thermoelectric effects, the joints should be allowed to cool before the meter is checked with one known to be accurate. The size of the wire used in the shunt should be large enough so that it does not heat appreciably, or thermoelectric effects will alter the reading every time the shunt is used. Since the shunt resistors have very low values, any contacts used in series with them must make very good connection or else the effective value of the shunt will be changed and the accuracy of the instrument lowered. There is also the other possibility to keep in mind: *i.e.*, if the shunt opens up, the entire current will flow through the movement with very disastrous results. For this reason, the switching scheme shown in Fig. 50 is not a satisfactory one to use in practice.

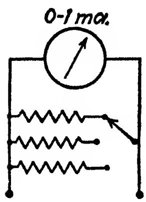


FIG. 50.—Theoretical diagram of a multiscale instrument.

The Ayrton Shunt.—The arrangement shown in Fig. 51 to obtain the various milliammeter scales is known as an "Ayrton shunt" after its inventor. It provides a very convenient and safe method of switching from one scale to another and is so arranged that both the milliammeter and voltmeter scales can be arranged on one multipoint switch. A 0-to-500-μa instrument is required if 1,000 ohms per volt is desired. The resistor in series with the instrument is used to bring the total resistance of the two to some even-hundred value. This simplifies the computations and allows most of the resistors to have values in ohms without fractions. The total value of the shunt resistor is the same as the instrument circuit. The value of the resistance for each shunt is found by dividing the total resistance in the circuit (shunt plus the instrument circuit) by n, which represents the number of times the instrument scale is to be multiplied. Thus, for the 600-ma. scale n would be 1,200 because 600 is 1,200 times the original instrument scale of $\frac{1}{2}$ ma. The total resistance in the circuit, 800 ohms divided by 1,200, gives 0.666

ohms for the shunt. In the same way, for the 60-ma. scale, n is 120 and the resistor should be 6.666 ohm; however, the 0.666 ohm is already there and so a 6-ohm resistor is used. The resistors

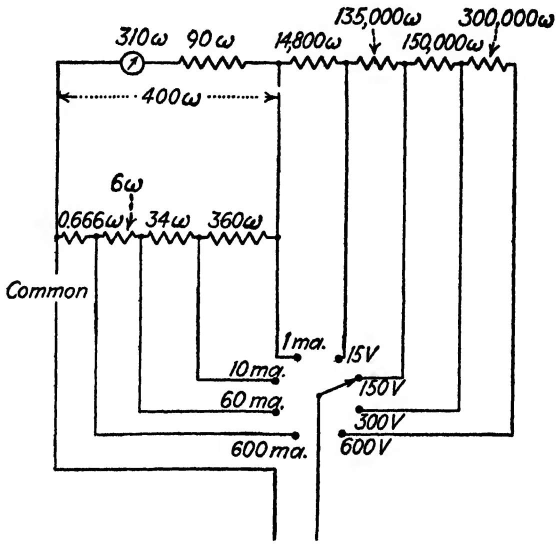


FIG. 51.—Circuit diagram of the Ayrton shunt combined with a voltmeter.

for the voltmeter scales are found in the usual manner. The resistance of the instrument is considered to be the parallel resistance of the instrument circuit and the shunt. In this case, it would be 200 ohms.

Ohmmeters.—The circuit of the simplest series ohmmeter is shown in Fig. 52. The value of the variable resistance is adjusted until the instrument reads exactly full scale when the test prods are shorted. The most accurate method of designating the scales on this meter is to specify the resistance reading at the center of the scale. The highest reading that can be made with any degree of accuracy will be about ten times the center reading. The lowest reading will be about one-tenth of that value. This circuit has one serious disadvantage in that, as the battery voltage drops, the resistance of the whole

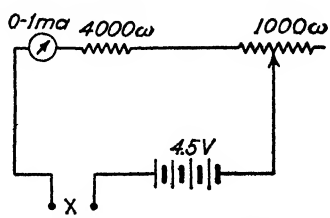


FIG. 52.—Circuit diagram of an ohmmeter for high resistances with series adjustment.

circuit is lowered and this shifts the reading at the center of the scale and thereby all the other points on the scale. To illustrate this point, let us assume that a new battery with a voltage of 4.5 is installed. The series resistance would then have to be 4,500 ohms to limit the current to 1 ma. A 4,500-ohm resistor across the test prods would now double the resistance in the circuit and the instrument would therefore read half scale and this point would be marked 4,500 ohms. After a period of use, the battery voltage might drop to 3.5 volts. In order to make the meter read full scale on short circuit (the test prods touching each other), the series resistance should be reduced to 3,500 ohms. Under these conditions a 3,500-ohm and not a 4,500-ohm resistor will cause the meter to read half scale. A 3,500-ohm resistor would then give an indication of 4,500 ohms on the scale. This would be an error of nearly 30 per cent.

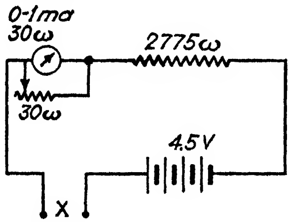


FIG. 53.—Circuit diagram of an ohmmeter for high resistances with shunt adjustment.

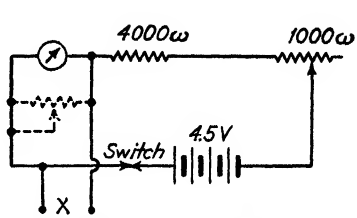


FIG. 54.—Circuit diagram of an ohmmeter for low resistances showing either series or shunt adjustment.

A much better method is to place the adjustable resistance across the instrument as shown in Fig. 53. In this circuit the total resistance does not vary so much as on the other when the adjustment is made and the error is so slight that it can be neglected for service work.

When resistance values of approximately one ohm are to be read, the circuit shown in Fig. 54 should be used. For extremely low values, the meter may be shunted with a resistance inside the case as shown by the dotted lines. Higher values of resistance can be read on the series ohmmeter by increasing the battery voltage and the series resistance so that the full-scale reading will be obtained when the test prods are shorted.

Wheatstone Bridge.—Many of the modern pieces of test equipment for measuring the values of resistances, capacities,

and inductances are based on the Wheatstone-bridge circuit. The circuit of an elementary Wheatstone bridge is shown in Fig. 55. The circuit consists of four impedances A, B, W, and X connected as shown. For the measurement of resistances, a battery is connected to the points C and D and a very sensitive current-indicating instrument is connected to the points E and F. The value of the resistance W is then varied until the instrument indicates no current. When this condition is attained, the bridge is said to be "balanced." This occurs when the resistances have the following relation to each other: $\frac{A}{B} = \frac{W}{X}$ or $X = \frac{BW}{A}$. In practice A and B, which are known as the ratio arms, are usually multiples of 10. Under these circumstances, if A is 10 or 100 times B, then W will be 10 or 100 times X, or if A is $\frac{1}{10}$ or $\frac{1}{100}$ of B, then W will be $\frac{1}{10}$ or $\frac{1}{100}$ of X.

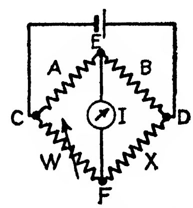


FIG. 55.—Elementary circuit diagram of Wheatstone bridge.

For the measurement of capacity and inductance, a variable capacity or a variable inductance must be substituted for the resistor W and a source of alternating current substituted for the battery. The current-indicating instrument is replaced by a pair of phones and in some instances by a 6E5 or 6U5/6G5 tube. In some of the commercial bridges, the impedance W consists of a number of resistors, condensers, and inductances any one of which can be selected by means of a multipoint switch. The ratio arms are then replaced by a potentiometer. A pointer on the potentiometer shaft can then be calibrated directly to indicate the capacity, resistance, or inductance as the case may be. There will be a separate scale for each of the impedances in the W arm. The circuit of such a bridge is shown in Fig. 56. D is a source of alternating current, which may be the 60-cycle lighting circuit or an audio oscillator. If an audio oscillator is employed, more accurate results will be obtained if approximately 1,000 cycles is used because the ear is particularly sensitive to this frequency. The resistance C is used to compensate for the fact that when two condensers are being compared a zero indication cannot be obtained unless the resistances of the two condensers as well as the capacity are the same. To accomplish this, the

resistance is put in series with the one having the lower resistance. As the resistance is a measure of the power factor of the condenser, this resistor can be calibrated in terms of power factor. The pointer E indicates directly the resistance, capacity, or inductance being measured when the bridge is balanced. When small capacities are being measured, it is necessary to find the capacity of the leads by placing them in the same position in which they were when connected to the condenser but leaving them open circuited. The capacity thus found should be subtracted from the total indicated for the condenser.

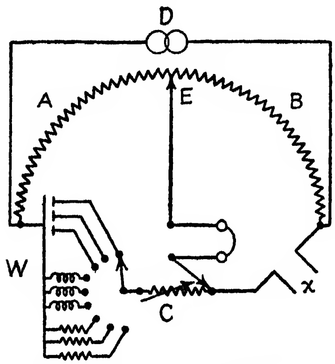


FIG. 56.—Circuit diagram of the potentiometer-type Wheatstone bridge.

Radio- and Intermediate-frequency Test Oscillators.—A satisfactory r-f test oscillator must have stability, must be modulated, and must have an attenuator that can cut the output from maximum to zero without changing the frequency. The r-f output of an oscillator must be modulated by an a-f signal; otherwise there would be no a-f output to cause a reading on the output meter or to give a vertical deflection on the cathode-ray oscillograph if it is being used. The term "stability" is applied to that property of an oscillator that enables it to maintain oscillation at a fixed frequency. In other words, a stable oscillator will not change its calibration. Instability in an oscillator is caused by temperature changes, changes in the load on the oscillator, variations in the voltages impressed on the tube, and variations in the circuits connected to the tube.

Methods of Increasing the Stability of Oscillators.—The use of the grid-leak grid-condenser method of obtaining the bias on the tube rather than a cathode resistor or a battery bias will increase the stability. The value of the grid resistor should be as high as possible and still avoid intermittent operation. The placing of a high resistance between the plate of the tube and the tuned circuit also increases the stability. The tuned circuit should also have a high Q.

The Q of a coil is defined as the ratio of the inductive reactance to the resistance. Of two coils having the same inductive reactance the one having the less resistance would have the higher Q. The greater the inductance of the coil in proportion to its resistance, the higher its Q will be. From this it can be seen that a high Q coil will tune sharply, whereas a low Q coil will be much broader tuned. For this reason, the Q of a coil is a measure of the worth of the coil. The r-f resistance of a tuned circuit can be kept low by using litz wire in the coil, by using the highest quality of insulation in the coil form and in the condenser, and by using the least possible amount of dielectric material in each. The load must be as light as possible as it has the effect of adding resistance to the tuned circuit.

Figure 57 shows a method of reducing the effect of changes in the tube on the oscillator frequency. Diagram (*a*) gives the diagram of the usual Hartley circuit. Diagram (*b*) shows the changes required to reduce the effect of the tube. The resultant circuit is apt to break into parasitic oscillations but these can be suppressed by inserting a resistance in the plate or grid circuit close to the tube. The value of this resistance will vary from 50 to 25,000 ohms, depending on circuit conditions. It should be noninductive.

Attenuation of the Oscillator Output.—In receivers having a.v.c., it is essential that the signal from the test oscillator be so weak that it does not cause the a.v.c. to go into action; otherwise the indications of the output meter will be unreliable. In order to limit the amount of signal reaching the receiver, it is absolutely necessary that the oscillator be thoroughly shielded and that it be provided with an attenuator. The design and construction of a suitable attentuator are often the hardest parts in the construction of an oscillator. The main difficulty is in preventing the attenuator from having an effect on the frequency. In all cases, it will be necessary to shield the attenuator from the other parts of the oscillator.

In order to maintain the calibration of the oscillator, the wiring and parts must be rigid. Bus-bar wiring is recommended on this account. The attenuator should have a special shield around it that must be insulated from the main shield except at one spot, where it should be thoroughly soldered to the main shield.

The foregoing statements on oscillator construction are not given with the idea of encouraging the serviceman to build his own test oscillator, for homemade test oscillators seldom have sufficient stability to be of any practical use. The statements should enable the serviceman to make an intelligent choice of the many oscillators on the market.

Calibrating the Oscillator.—The serviceman can check all bands on his oscillator by using local stations as his source of standard frequencies. These standards will be much more accurate than any other source that is ordinarily available.

An all-wave receiver is required if the h-f bands are to be checked. Any broadcast receiver can be used for the broadcast and i-f bands.

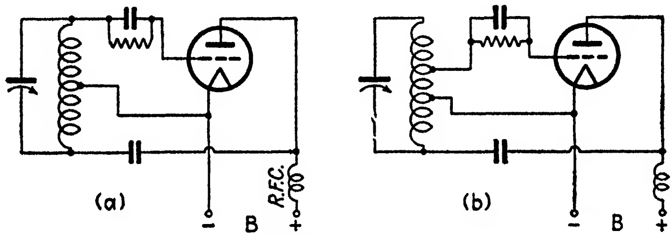


Fig. 57.—Hartley oscillator circuits.

The procedure is as follows:

Connect the receiver to an antenna.

Connect the oscillator across the antenna and ground terminals of the set.

The calibration of the broadcast band of the oscillator can now be checked by tuning in any number of stations on the receiver and then tuning the oscillator (unmodulated) until a whistle is heard. This whistle is caused by the heterodyne of the oscillator frequency with the station frequency. The frequency or pitch of the whistle will always be the difference between the station frequency and the oscillator frequency. Continue to tune the oscillator so that the frequency of the whistle goes down and finally stops. This is known as "zero beat." If you continue to rotate the oscillator dial, the whistle will reappear and will become higher and higher in frequency. At the "zero-beat" point, the oscillator is exactly on the station frequency. The oscillator dial reading can then be checked.

As many stations as can be tuned in on the receiver can be used to check points on the oscillator dial. It is well to check a reasonable number of stations spread over the entire scale, for the variation of the readings from correct amounts will vary at different parts of the dial. The readings are often high at one part of the dial and low at some other point.

The connections for the check of the i-f bands are the same as for the broadcast band. The procedure for this test can best be illustrated by an example. Start with any local station frequency, *e.g.*, that of KMOX, 1,120 kc. Divide that frequency by 2, 3, 4, 5, 6, 7, and 8, thus:

2)1,120	3)1,120	4)1,120	5)1,120	6)1,120	7)1,120	8)1,120
560	373.3	280	224	186.6	160	140

Tune in the station that you have chosen on the receiver. Now if the oscillator (unmodulated) is tuned to any of the frequencies found in the preceding division, the heterodyne whistle will be heard and the oscillator should be tuned to zero beat. In this test, it is a harmonic of the oscillator beating against the station. For example, if the receiver were tuned to KMOX on 1,120 kc. and the oscillator tuned to 224 kc., the fifth harmonic of the oscillator would be 1,120 kc., which would heterodyne with the station. When the fifth harmonic of the oscillator was exactly 1,120 kc., the fundamental would have to be one-fifth of 1,120 kc., or exactly 224 kc. Since the oscillator is already calibrated and the variations are seldom more than 20 kc., there would be no difficulty in telling which harmonic is being used.

An all-wave receiver is required to check the calibration of the h-f band. It is not necessary to have the dial of the receiver read absolutely correct; however, it should be reasonably accurate.

The connections are the same as for the previous tests. Proceed as follows: Tune the receiver to some local station. Tune the oscillator (unmodulated) to zero beat. The oscillator now has as a fundamental frequency, the frequency of the local station; however, it is also producing a large number of harmonic frequencies. For example, if the local station frequency was 800 kc., the oscillator would also be producing 1,600, 2,400, 3,200,

4,000, 4,800, 5,600 kc., etc. These same frequencies can be written 1.6, 2.4, 3.2, 4.0, 4.8, 5.6 mc., etc. Turn on the audio-modulation switch of the oscillator, and then tune the receiver until the modulation note is heard at or near 1.6 mc. on the receiver dial. Tune in the signal accurately with the tuning indicator or an output meter. The receiver is now tuned to 1.6 mc. accurately because the percentage of accuracy of the harmonic is the same as that of the fundamental and that accuracy has been checked against a station frequency, which seldom varies more than 25 cycles from its assigned frequency. Now tune the oscillator to approximately 1.6 mc. as indicated by its dial. Its modulation frequency should be heard in the receiver when the oscillator is tuned near this point. Tune the oscillator until the tuning indicator on the receiver indicates that it is in exact resonance. The oscillator is now tuned to exactly 1.6 mc. The oscillator calibration can be checked at 2.4 mc. by again tuning the receiver to the 800-kc. station, tuning the oscillator to zero beat, tuning the receiver accurately to the third harmonic of the oscillator (this will be near 2.4 mc. on the receiver dial), and then tuning the oscillator accurately to the receiver at approximately 2.4 mc. on the oscillator dial.

By using the frequencies of several broadcast stations as fundamentals, a large number of points on the oscillator dial can be checked.

Using the Harmonics of a Test Oscillator.—Fundamental frequencies should always be used when accuracy of calibration in a test is necessary. The accuracy of the harmonics is the same in percentage as that of the fundamental. This would mean that if the fundamental was 100 kc. and it was accurate to 1 per cent, the possible deviation might be 1,000 cycles. However, the tenth harmonic of this frequency or 1,000 kc. would be off 10 kc. If higher harmonics are used, the error increases and the calibration is of little use.

Audio Oscillators.—An audio oscillator is very useful in locating the source of rattles or buzzes in loud-speakers or in cabinets. The greatest difficulty in finding the cause of this type of trouble is to make the disturbance occur continuously so that the vibrating part can be located. With an audio oscillator adjusted to produce the particular frequency causing the difficulty, the trouble can be located by simply touching various parts of the

equipment. When the part causing the trouble is touched, it will usually stop vibrating. In the cheaper cabinets, loose and cracked panels are frequently the cause of noise. The application of a little carpenter's glue will stop the difficulty. If a panel is cracked, it is sometimes necessary to glue a strip of wood over the crack on the inside of the cabinet. This strip while drying should be held firmly in place by C clamps or heavy weights. In cone speakers having a long driving rod, vibration of this part can be prevented by slipping a piece of spaghetti tubing over it.

The circuit of an audio oscillator that will generate frequencies from one or two a minute to 12,000 per second is shown in Fig. 58.

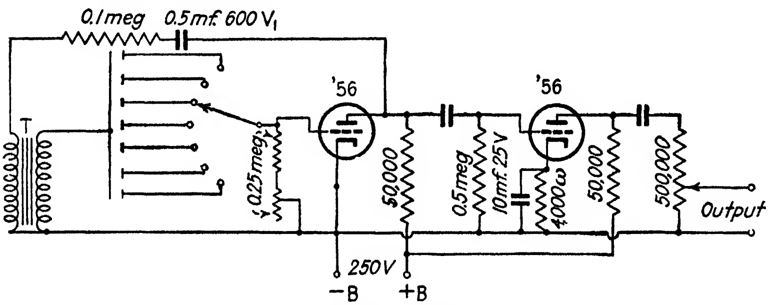


FIG. 58.—Circuit diagram of an audio oscillator.

T is an audio transformer that may be of the variety found in old battery sets. The grid condensers range from equalizing condensers for r-f tuning circuits for the high frequencies to 1- or 2-mf. condensers for the extremely low frequencies. The variable grid leak can be a 250,000-ohm volume control. It should have a pointer or dial on it if the oscillator is to be calibrated. The frequency is determined mainly by the values of the grid leak and the grid condenser. The output of this oscillator will be of comfortable headphone volume, so that a power amplifier will be necessary for work on speakers and cabinets. The volume control of the power amplifier should be used to control the output. If a volume control is desired on the oscillator, it will be necessary to add at least one stage of amplification between the control and the oscillator; otherwise the setting of the control will vary the frequency.

Owing to the variations in condensers and resistors, it is impossible to give the calibration of an audio oscillator; however,

an audio oscillator can be calibrated by tuning it to some musical instrument, preferably a piano that is known to be accurate. The audio frequencies corresponding to the notes on a piano are given in the Appendix.

The oscillator described above has one serious drawback. It does not have a pure sine-wave output. For tracing down buzzes and rattles this is of no consequence. The beat-frequency oscillator does have a pure or very nearly pure sine-wave output. The exact shape of the output wave can be examined with a cathode-ray oscillograph. If it is then fed into an audio amplifier

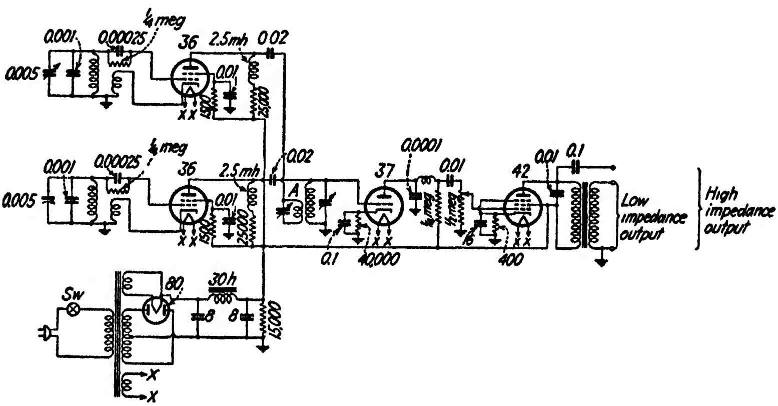


FIG. 59.—Circuit diagram of a beat-frequency oscillator.

and the wave shape at various stages in the amplifier is examined, the location of any distortion can be readily found. This subject will be covered more thoroughly in Chap. XIV. The circuit of a beat-frequency oscillator is shown in Fig. 59. The principle of its operation is the same as that of a superheterodyne.

The two 36 tubes are oscillating at some i-f frequency. Transformers of 175 kc. were used for the coils. This frequency would be more stable than the higher i-f frequencies popular at present. The upper tube operates at a fixed frequency while the frequency of the lower one is controlled by the 0.0005 tuning condenser. The transformer *A* must be very carefully peaked at the frequency of the fixed oscillator. It should be a duplicate of the two used in the oscillator circuits. It is particularly important to shield the two oscillators from each other. For this reason it is a good plan to place the detector tube, the 37,

between the oscillators. If a transformer having 2.5-volt windings is available, 24's can be substituted for the 36's, a 27 or 56 for the 37, and a 47 for the 42. Any of the rectifiers used in radio sets may be used in the power supply.

Vacuum-tube Voltmeter.—The vacuum-tube voltmeter is rapidly becoming a necessity in radio and public-address service work. With it the serviceman can read voltages without disturbing the circuits to which the instrument is connected. For example, the a.v.c. voltage developed by a diode can be read and the changes in its value watched as the signal is increased or decreased. Signal voltages, whether r-f, i-f, or a-f, can be read

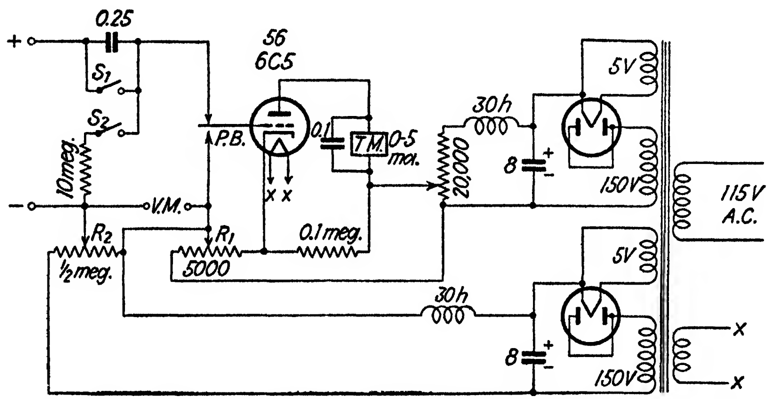


Fig. 60.—Circuit diagram of a slide-back-type vacuum-tube voltmeter.

at any point in a circuit. This is the basis of the method of servicing known as "signal tracing." The plate and grid voltages in resistance-coupled amplifiers can be accurately determined. The frequency characteristics of an amplifier can be determined by feeding a very weak but constant audio signal from an oscillator into the amplifier and reading the output voltage with a vacuum-tube voltmeter. The input voltage can be kept constant with the same meter by using a d.p.d.t. (double-pole, double-throw) switch. The input is connected to one set of switch clips, the output to the other, and the vacuum-tube voltmeter to the switch blades. Most output meters are not suitable for this purpose because their calibration varies with the frequency. A circuit diagram of a vacuum-tube voltmeter suitable for service work is shown in Fig. 60. The plate voltage of the tube should

be approximately 90 volts. The voltmeter in a set analyzer may be connected to the terminals marked voltmeter, or a multiscale voltmeter, reading from 0 to 200 volts, may be built in. When a-c voltage readings are desired and d-c voltages are also present, the alternating current may be obtained by opening

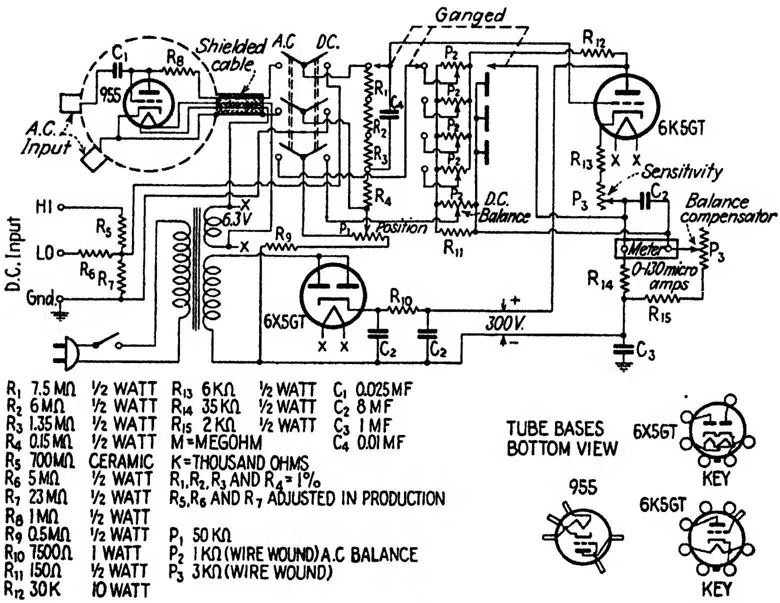


FIG. 61.—Circuit diagram of the Hickok Model 110 vacuum-tube voltmeter. (*Courtesy of the Hickok Electrical Instrument Co.*)

the toggle switch *S*1. The meter *TM* may be a 0–5 ma. tuning meter.

To operate the vacuum-tube voltmeter, the voltmeter should be set on a scale reading to 200 volts at least. R_1 should be adjusted to full resistance, the arm of R_2 moved to the left, and then the a-c switch turned on. Depress push button *PB*, and adjust R_1 until the plate current of the 56 tube is very near zero. The exact reading of the tuning meter should be noted. Then release push button *PB*. The terminals of the vacuum-tube voltmeter are then connected to the source of voltage to be measured and the potentiometer R_2 adjusted until the reading of the tuning meter returns to the near-zero reading previously

noted. The voltmeter then will indicate the voltage across the terminals. Direct-current voltages should be connected as shown in the diagram. The voltmeter will then indicate the exact voltage. In the case of a-c voltages, peak voltages will be indicated. To reduce these to readings corresponding to ordinary a-c voltmeter readings, multiply the peak value, as indicated by the vacuum-tube voltmeter, by 0.707.

One drawback to this type of vacuum-tube voltmeter is that it is not easy to follow a varying voltage such as the a.v.c. voltage as the signal strength is changed. There are vacuum-tube voltmeters on the market that indicate the voltage like an ordinary instrument and do not require any slide-back adjustment before the reading can be made. The diagram of one of these is shown in Fig. 61. When signal voltages on the grids of tubes or across tuned circuits are to be ascertained, the capacity between the test leads and their shields should be minimized or an entirely erroneous indication will be obtained. This difficulty is usually overcome by placing an extremely small condenser at the tip of the test probe.

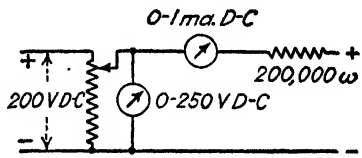


Fig. 62.—Circuit diagram of a zero-current voltmeter.

Figure 62 shows a circuit that may be used to read d-c voltages without drawing current from the circuit being measured.

To operate this device, set the potentiometer to approximately the voltage to be measured, and connect the test prods across the voltage. If either the voltage across the potentiometer or the unknown voltage is higher than the other, the milliammeter will indicate current. Adjust the potentiometer so that the milliammeter indicates no current, and then read the voltmeter. It is essential that the voltmeter be connected while the potentiometer is adjusted. The 200,000-ohm resistor in series with the milliammeter prevents more than 1 ma. from passing through the meter unless the unknown voltage is more than 200 volts greater than the voltage across the portion of the potentiometer below the arm. Higher voltages may be read by increasing the voltage across the potentiometer and at the same time increasing the resistance in series with the milliammeter. This resistor should be 1,000 times the value of the highest voltage that it is desired to measure.

This device will not work on alternating current even if alternating current is placed across the resistor because there would be, except in rare instances, a phase difference between the two voltages which would lead to inaccuracies at least and to short circuits in some cases.

Output Meters.—An output meter consists of some device for rectifying the a-f current and an instrument to measure the quantity of current rectified. The commercial meters usually employ a copper oxide rectifier. The 1,000 ohms per volt rectifier-type a-c voltmeters found on some of the set analyzers can be used very satisfactorily as an output meter. Owing to the capacity between the plates of the rectifiers of these meters, which by-pass the higher frequencies, they cannot be used to compare voltages of two different frequencies. The difficulty can also be stated in this way: Because of the by-passing effect of the capacity of the rectifier, the calibration of the meter will be different for each frequency for which it is used. This condition does not in any way interfere with the use of the meter as an output meter because when used for this purpose only a single frequency is being measured and only comparative readings are required.

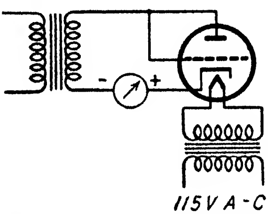


FIG. 63.—Circuit diagram of an output meter.

When a rectifier-type meter is used as an output meter and is connected from the plate of a tube to ground, a condenser should be used to block the d-c voltage. It is possible to use a higher scale on the meter and avoid the use of the condenser, but this will make the variation in the readings due to the changes in the alignment of the set very small in proportion to the reading and therefore not so easy to detect.

To construct an output meter for use on the test bench, the circuit shown in Fig. 63 may be used to advantage. Almost any type of tube may be used. For a-c operation, a 56 or 6C5 tube is recommended. For direct current any of the battery tubes will be satisfactory. The transformer should be as near a 1:1 ratio as is possible. An output transformer to connect almost any tube to a magnetic speaker will be satisfactory. The full-scale reading of the meter will depend on the transformer used. However, a 0- to 10-ma. d-c instrument usually will be

satisfactory. This meter should be used from plate to ground. It is not satisfactory if connected to the voice coil.

Output-meter Connections.—The easiest place to connect the output meter is across the voice-coil leads. However, in some cases this will not give sufficient reading on the meter unless the test oscillator is so strong that it interferes with the a.v.c. action. In this case, it is necessary to connect the output meter between the plate of the output tube and the chassis. Since there is a high d-c potential between these points, it is necessary to insert a condenser in this circuit to prevent damage to the meter. In the case of a push-pull output stage, the connection is made from either plate to ground as in the case of a single tube, or the meter may be connected from plate to plate of the output tubes. In the latter case, the use of the condenser is optional as the two plates are at the same d-c potential.

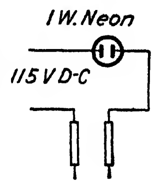


Fig. 64.—Circuit diagram of a condenser tester.

Condenser Tester.—For testing condensers for leakage and open circuit, the device shown schematically in Fig. 64 is recommended. It operates in the following manner. The charging current of a good condenser will cause the neon tube to flash. If the condenser is leaky even to the slightest extent, the tube will continue to flash. The rapidity of the flashes increases as the leakage increases. A steady glow indicates a shorted condenser. This device is really more sensitive then necessary for most radio work. A condenser will usually be found satisfactory if its resistance is in excess of ten times the value of the resistor across it; however, it must be remembered that a slight leak may indicate the beginning of a complete breakdown of the condenser, and the installation of a new condenser may prevent a call back.

If 115 volts d-c is not available, any well-filtered power supply can be used. However, if there is even a little ripple left in the output, it will pass through the condenser on test and cause the neon light to flicker even if the condenser is perfect. Even with 115 volts d-c it may be found that the light will flicker due to the commutator ripple usually found in this source of power. In either case additional filtering will solve the difficulty.

There are several condenser analyzers on the market. Several of them use a Wheatstone-bridge circuit as illustrated by the Solar Dynamic Capacitor checker shown in Fig. 65.

The bridge circuit used is very similar to the one shown in Fig. 56. The 6U5/6G5 tube is used as the null or balance indicator. The three upper contacts on the switch *S* are used to select the proper standard condenser. When the switch *S* is in its lowest position and the switches *S*1, *S*2, and *S*3 are set as shown in the diagram, *S*1 and *S*3 connect any condenser put across the test prods in a tuned circuit coupled to the oscillator. A good condenser will allow the oscillator to work and the voltage developed across the grid leak will close the "eye" of the 6U5/6G5. A leaky condenser will cause the eye to wink or flicker. If the eye does not operate at all, an open condenser is indicated.

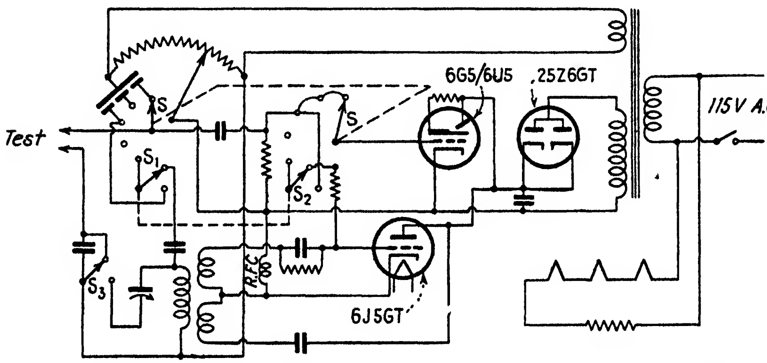


Fig. 65.—Circuit diagram of the Solar Dynamic Capacitor checker Model BQC.

An entirely different principle is used in the Aerovox 95 L-C checker shown in Fig. 66. This equipment consists of a 6J5G oscillator which covers a wide band of frequencies with six coils and a 6E5 tuning indicator that is operated by the voltage across the oscillator grid leak. If the probes are put across a condenser, that condenser in series with the 5-mmf. condenser is in parallel with the tuning condenser and this changes the tuning of the circuit. When the tuning condenser dial is rotated to bring the circuit back to resonance, the change in the capacity as shown by the dial will be the capacity of the condenser under test.

When the loop is coupled to a tuned circuit, the tuned circuit will absorb energy from the oscillator circuit if it is tuned to the same frequency. This results in a reduction in the voltage across the grid leak and therefore the shadow on the tuning

eye widens. Since the dial of the tuning condenser is also calibrated in frequency, the frequency of the circuit being tested can be read. This equipment can also be used in the alignment of r-f and i-f circuits, in checking the alignment of oscillators in superheterodyne circuits, in tuning wave traps, and for many other similar purposes.

There is one place in a radio circuit where a perfect condenser is essential, and that is the blocking condenser, which

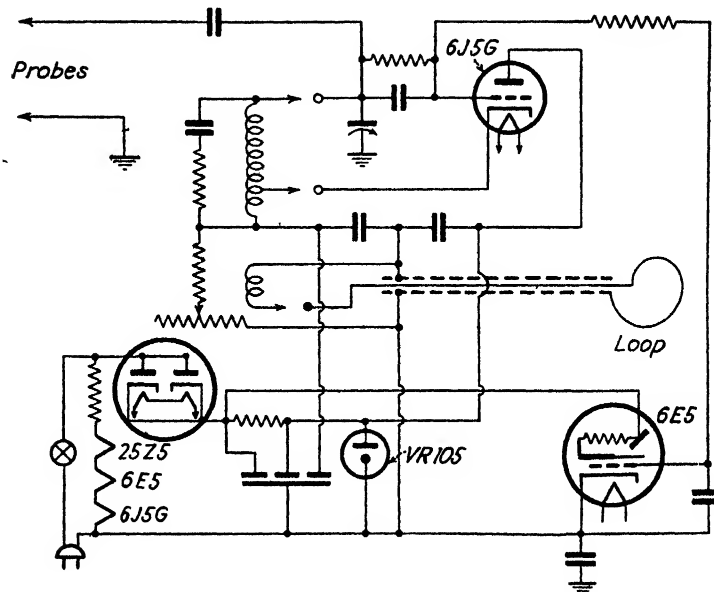


FIG. 66.—Circuit diagram of the Aerovox 95 L-C checker.

keeps the plate voltage of one tube off the grid of the following tube in a resistance-coupled amplifier. The slightest leakage in this condenser will seriously interfere with the operation of the amplifier.

Electrolytic-condenser Tester.—The equipment for testing electrolytic condensers is not so simple as that for paper condensers because of the necessity of polarizing the condenser at all times. The Aerovox Corporation, one of the large manufacturers of electrolytic condensers, recommends the circuit shown in Fig. 67 for condensers with a voltage rating in excess of 300 volts. The polarizing d-c voltage should be adjusted to be

just below the rated voltage of the condenser. This circuit is nearly foolproof, for the 2,000-ohm resistor limits the current from the d-c source, which may be batteries or a power supply, and the 4-mf. condenser limits the current drawn from the a-c source. To use the equipment, the a-c plug should be left

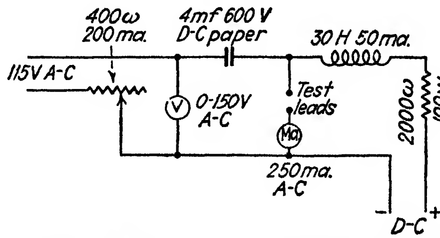


FIG. 67.—Circuit diagram of an electrolytic-condenser tester.

disconnected and the d-c source connected. The current will be high at first but should soon drop to from 0.05 to 0.5 ma. per microfarad. When the current has dropped to this value, the alternating current can be connected and the voltage adjusted by means of the 400-ohm rheostat to 100 volts. The reading on the milliammeter will then give the capacity when applied to the chart shown in Fig. 68.

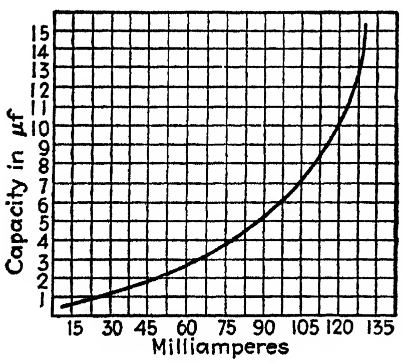


FIG. 68.—Calibration chart for the circuit shown in Fig. 67.

The most satisfactory test for electrolytic condensers is to substitute another one and determine whether the difficulty is remedied. Electrolytic condensers can also be checked with an ohmmeter. Read the resistance across the terminals and then reverse the probes and read the resistance again. Unless one reading is ten times or more than the other, the condenser should be replaced.

Tube Checkers.—In selecting a tube checker, one should be chosen that checks the mutual conductance of the tube. This is the recommendation of the tube manufacturers. A check should be made to see that the sockets and switches will stand up under

continual use and that the sockets, particularly, can be replaced easily, for they will need to be replaced if the checker is used constantly. It is always easier to convince a customer that a tube needs replacing if one of the testers is used which has the good and bad portions of the dial plainly marked.

Since none of the tube checkers on the market is infallible, it is a very good plan to use the substitution method in checking

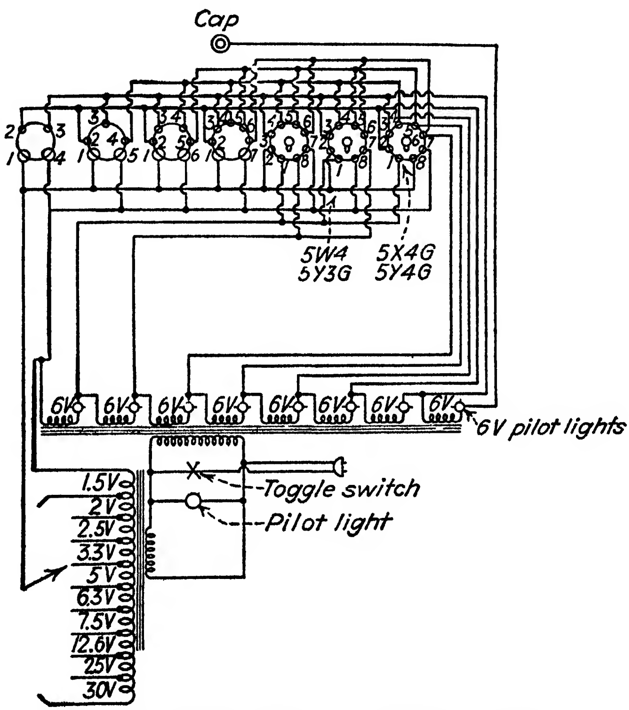


FIG. 69.—Circuit diagram of a tube short checker.

tubes. Replace all the tubes in the set with those known to be good and then replace the old ones one at a time. Any decrease, in the volume or the appearance of any distortion when one of the old tubes is inserted is the best possible check on the worth of the tube.

Test for Gas in Radio Tubes.—If gas is present in a tube, grid current will flow. The direction of the current will depend on the structure of the tube and on the voltages on all the elements in it; however, the direction is not important—the fact that grid

current flows is important. This grid current can be detected by inserting a resistor of approximately 500,000 ohms in the grid circuit with a switch across it to short it out. If the tube is gassy, the current flowing in this resistor will cause a voltage drop that will alter the plate current as the short-circuiting switch is opened and closed.

Tube Short Checkers.—Most commercial tube checkers are protected against shorts in the tubes by means of fuses. To avoid the constant renewal of the fuse, it is advisable to check the tube for shorts before it is placed in the tester. A circuit for a short checker, which is recommended by one of the large tube manufacturers, is shown in Fig. 69.

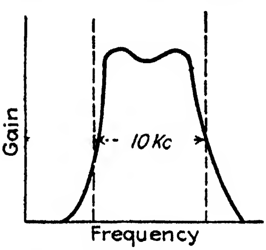


FIG. 70.—The correct frequency-vs.-gain curve for an intermediate-frequency amplifier.

The tubes should be checked for shorts when hot as well as when cold because the expansion that occurs when the tube heats up sometimes causes the short. Six-volt pilot lights are used in preference to the $2\frac{1}{2}$-volt variety because they use less current and operate on a higher voltage, which enables them to show a higher resistance short than the lower voltage higher current lights. If a large enough core is used, the two transformers can be combined. Design data for the transformer will be found in Chap. VI.

Cathode-ray Oscillograph.—The cathode-ray oscillograph is by no means a new development, but not until the advent of the high-fidelity receiver did it present any marked advantages over the other types of service equipment. Probably the most distinguishing feature of the high-fidelity receiver is the frequency-versus-gain curve characteristic of the i-f amplifier. When the proper adjustment is made, the curve should be as shown in Fig. 70. Notice particularly the broad top that is responsible for the high fidelity of the receiver. Because this top is broad, it is impossible to secure the proper adjustment with an oscillator and output meter, for tuning within the range of the flat top will not change the indications of these instruments. The curves shown in Fig. 71 are the usual result of an attempt to adjust the i-f amplifier of a high-fidelity receiver without the aid of an oscillograph. The conditions indicated by these curves seriously affect the fidelity of the receiver.

In an elementary way, the cathode-ray tube is like the ordinary radio tube. It has a heater, cathode, grid, and plate or high-voltage anode, which functions in much the same manner as those of a triode. The cathode emits electrons that are attracted by the high positive charge on the plate. The grid is used as a

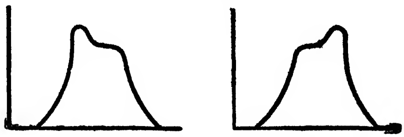


FIG. 71.—Improper frequency-vs-gain curves often obtained by the use of the oscillator-output-meter method of alignment.

control member to regulate the flow of electrons to the plate. The position of the elements is somewhat different from that of the elements in the conventional tube in that the plate, which is a small tube, is placed so that the cathode is in line with its axis but some distance from the end of the tube. The grid is placed between the cathode and the plate, as is customary.

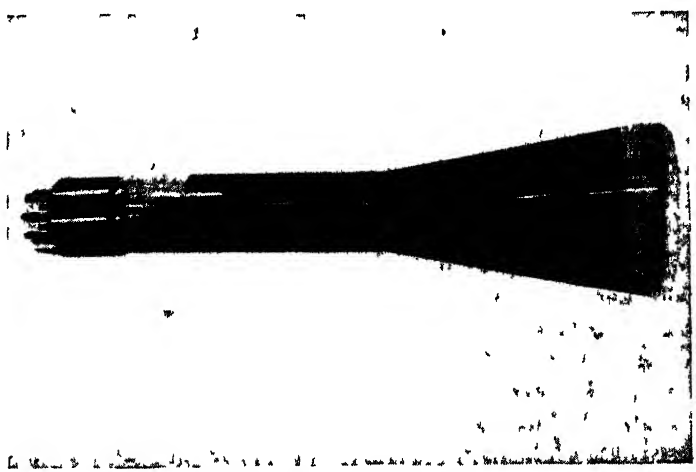


FIG. 72.—Cathode-ray oscilloscope tube type 3AP1/906-P1.

The focusing anode is also inserted in this space. The relative positions of the various parts of the tube are shown in Fig. 73.

In operation, the cathode emits electrons that are attracted by the plate; however, comparatively few of them stop at the plate. Most of the electrons continue through the tubular plate and

strike the end of the tube, which is covered with a salt that emits light when electrons strike it. The stream of electrons causes a spot of light to appear on the end of the tube. The brilliancy of the spot is governed by the number of electrons striking the end of the tube, which is, in turn, controlled by the grid voltage. The size and the sharpness of the outline of the spot are controlled by the voltage on the second grid in the tube. The deflecting plates, four in number, are arranged as if on the sides of a square with the stream of electrons passing through the center. The plates on opposite sides of the square are used in pairs. One plate is always positive when the other is negative; therefore, the positive plate attracts the electron stream whereas the opposite plate repels it. One set of plates deflects the stream in a

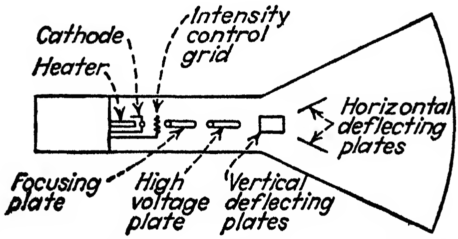


FIG. 73.—Diagram showing the construction of a cathode-ray oscilloscope.

horizontal direction whereas the other set causes a deflection in a vertical direction. Since the electron stream has practically no weight or inertia, it is capable of deflecting at high frequencies, a property not possessed by any other indicating device.

Voltage Measurement.—If a sine-wave voltage of any frequency is placed on the vertical plates, the movement of the beam will cause a vertical streak of light to appear on the screen. The magnitude of the peak voltage can be determined by measuring the length of the line. Figure 74 illustrates the pattern shown by the tube when a sine-wave voltage is applied to the horizontal plates. Figure 75 illustrates the same condition on the vertical plates. In either figure, as the voltage changes from 0 to the point marked 1 on the sine wave, the spot of light will move from 0 to the point marked 1 on the tube. As the voltage travels from point to point on the curve, the point of light will move to the corresponding point on the tube. Owing to the fact that the eye retains an image for about $\frac{1}{20}$ sec. after

it has gone, the spot seems to be in all its positions at the same time, provided that the entire cycle is completed in less than $\frac{1}{20}$ sec. The pattern on the tube, then, is a straight line whose length is the distance between the positive and negative peaks. The peak voltage will then be one-half the length, and the r.m.s. voltage or the voltage as read on the ordinary meter would be half the length multiplied by 0.707. The oscillograph used in this manner is very useful in measuring the r-f voltages at the various stages in an r-f amplifier because any inefficient or

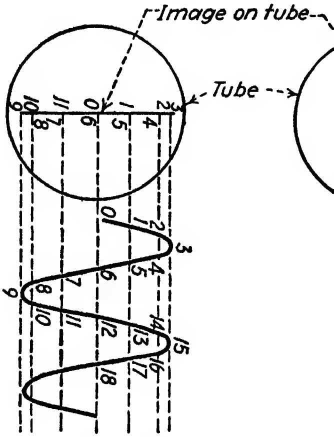


FIG. 74.—Image produced by a sine-wave voltage on the horizontal plates.

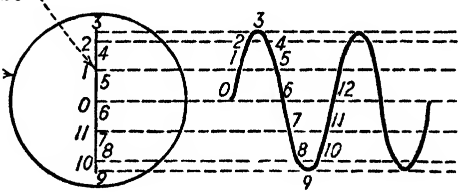


FIG. 75.—Image produced by a sine-wave voltage on the vertical plates.

defective stages are very easily discovered. Shorted tuning condensers or defective equalizing condensers and open or shorted tuning coils are indicated very clearly by a lack of an increase in the voltage as it passes through the stage. The use of an oscillograph is not limited to r-f stages but is equally effective in audio amplifiers and can even be used to determine if an oscillator is working. In all these cases, the voltage can be read from the plate of the tube to ground. The input voltage of a stage can be considered to be the signal voltage in the plate circuit of the preceding stage.

Examination of Wave Shape.—No indication of the wave shape can be secured by the use of the oscillograph in the manner discussed previously. To achieve this result, it is necessary to

move the spot across the tube horizontally as it is moved vertically by the voltage under investigation. Furthermore, the spot must start across horizontally each time that it starts up

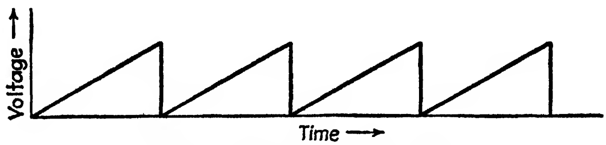


FIG. 76.—Saw-tooth wave shape.

and must move with a constant velocity in a horizontal direction. These conditions are met by the use of an oscillator having a saw-tooth wave-shaped output, which is connected to the horizontal deflection plates. The output voltage of this type of

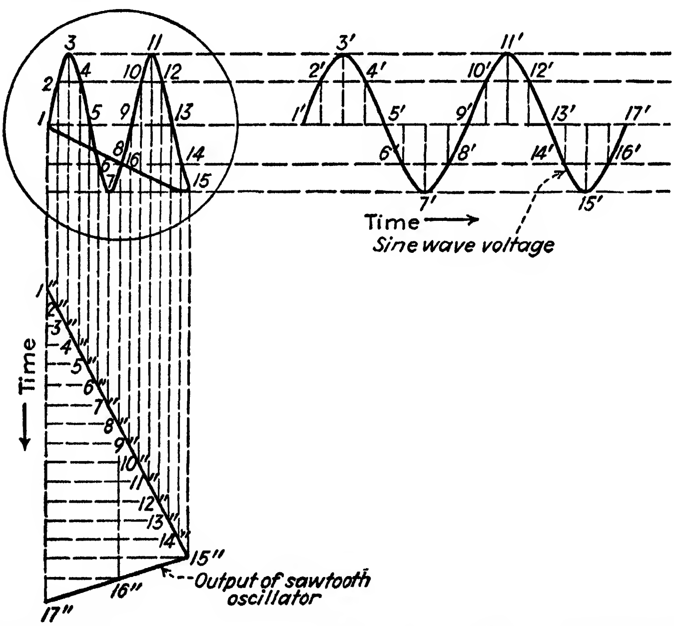


FIG. 77.—Image produced by the application of a sine wave to the vertical plates and a saw-tooth wave to the horizontal plates.

oscillator is shown in Fig. 76. Figure 77 illustrates the resulting figure on the tube when a sine wave is impressed on the vertical plates.

At the initial position, the horizontal voltage, which for brevity will be called the h voltage, is at its O value, which pulls the spot to the left. At this time, the value of the voltage to be investigated, hereafter called the "v" voltage, is zero. The spot then will be at the position 1 on the screen. At the time interval 2, the h voltage has increased to the value $2''$ and the v voltage increased to $2'$. The h voltage allows the spot to move toward the center of the screen, but the v voltage forces it upward so that it reaches the point 2 on the screen. By a study of the drawing, it will be seen that the combined effect of two voltages causes the spot to form the figure shown on the screen. The line on the screen between 15 and 17 is caused by the sudden change in the oscillator voltage from $15''$ to $17''$.

REVIEW QUESTIONS

4-1. Show by a diagram the tube-prong numbering system.

4-2. How can Loktal tubes be removed from the sockets?

4-3. Give the color code for resistors.

4-4. Show a diagram of a voltmeter with at least two scales.

4-5. Why cannot a D'Arsonval movement be used to measure alternating current?

4-6. What two types of meters can be used to measure high-frequency current?

4-7. Describe the electrodynamometer type of movement.

4-8. Why can it not be used for r-f currents?

4-9. Show a diagram of a circuit for measuring 10 ma. with a 0-1 ma. movement having 50 ohms resistance. State sizes of all parts used.

4-10. Show a diagram of an ohmmeter for measuring high resistances.

4-11. Show a diagram of an ohmmeter for measuring low resistances.

4-12. (*a*) Show circuits for getting a zero adjustment as the battery voltage varies.

(*b*) Explain the advantages and disadvantages of each.

4-13. Show the circuit diagram of a simple Wheatstone bridge.

4-14. What is meant by the term "oscillator stability"?

4-15. Give at least two methods or schemes for increasing the stability of an oscillator.

4-16. What is the Q of a coil?

4-17. What properties of a coil affect its Q?

4-18. Describe a method of calibrating a test oscillator on the broadcast band.

4-19. Describe a method of calibrating a test oscillator on the i-f band.

4-20. Describe a method of calibrating a test oscillator on the h-f bands.

4-21. Why is it not good practice to use the harmonics of a test oscillator?

4-22. Name two uses for an audio oscillator.

4-23. What is a beat-frequency oscillator?

4-24. What advantages does a beat-frequency oscillator have over other types?

4-25. What is the main advantage of a vacuum-tube voltmeter over a D'Arsonval movement?

4-26. (*a*) Show a circuit of a zero-current meter. (*b*) What types of current can it measure?

4-27. What disadvantage has a slide-back type of vacuum-tube voltmeter?

4-28. Show at least two methods of connecting an audio-type output meter to a set.

4-29. Give a satisfactory method of testing electrolytic condensers.

CHAPTER V

THEORY OF RADIO-FREQUENCY AMPLIFIERS

Radio-frequency amplification has several advantages: (1) Since the amplifier is designed for radio frequencies, it does not amplify 60-cycle hum or its harmonics as an audio amplifier would. (2) Radio-frequency transformers are much lighter and cheaper to build than audio transformers. (3) A very weak r-f signal can be amplified until it is large enough for successful detection.

Theoretically, r-f amplification appears very satisfactory; but, when the attempt is made to use it, complications or difficulties quickly arise. Some of the causes as well as the solution of these difficulties are explained below.

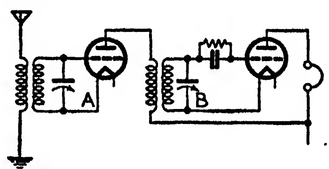


Fig. 78.—Elementary circuit diagram of a radio-frequency amplifier.

The cause of difficulties: Consider the theoretical r-f amplifier shown in Fig. 78. In tuning such an amplifier, it will be found that with stage *A* tuned to some broadcast station, as stage *B* approaches resonance with stage *A*, a whistle will be heard. This whistling indicates that the first stage has become an oscillator whose frequency is near that of the station to which it is tuned and with which it is mixing. Any circuit will oscillate if the plate circuit feeds back enough energy to the grid circuit to take care of all the losses in the grid circuit due to resistance, etc. In the circuit shown in Fig. 78, as stage *B* nears resonance with stage *A*, the transfer of energy from one to the other increases, as was shown in Chap. II. This accounts for the oscillation as the circuits are tuned together.

Regeneration is exactly the same action. It supplies energy to the grid circuit to make up for the loss due to poor insulation, resistance, or any other cause.

Many ways of controlling this feedback have been devised. Controlled feedback is often desirable, but uncontrolled feedback renders an amplifier useless.

Grid-resistor Method of Regeneration Control.—The most obvious method of preventing oscillation is to increase the losses in the grid circuit until the feedback cannot overcome them. This is done by putting resistances in the grid circuit to increase the loss. If too large a resistance is used, the volume will be needlessly reduced.

Reversed Capacity Control.—This is the well-known neutrodyne circuit, which is shown in Fig. 79. Since the voltage in the secondary S is in the opposite direction from that in the primary, if part of it is fed back through the condenser C into the grid circuit and its value adjusted by varying the condenser C, it will balance out any feed-back voltage coming through the grid-plate capacity. In practice it is impossible to obtain this balance for all broadcast wave lengths. However, if the oscillation is prevented at the h-f end of the band, there will be even less possibility of oscillation at the l-f end. Too much neutralization will result in weak signals at the l-f end of the band.

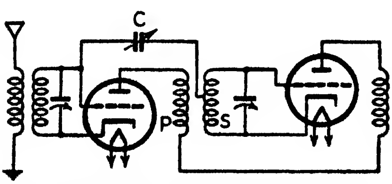


FIG. 79.—Circuit diagram of a neutrodyne circuit.

The several r-f transformers must be so placed that there is no magnetic coupling between them; otherwise stabilization cannot be achieved. The condenser C is of very small capacity; often it is just an insulated wire in a metal tube. The problem of oscillation in modern receiver circuits is solved by the use of screen-grid tubes.

Developments and Refinements in Radio-frequency Amplifiers.—The first r-f amplifiers were coupled to the antenna by a coil consisting of 6 to 20 turns wound directly over the ground end of the secondary or separated from it by $\frac{1}{8}$ or $\frac{1}{16}$ in. This circuit is shown schematically in Fig. 80. The capacity of the antenna in this circuit seriously affects the tuning of the secondary. Many sets having this type of antenna coupling have a knob on the panel controlling a small condenser connected across the first tuning condenser to compensate for the effect of the antenna. Placing a very small condenser in series with the antenna has a tendency to fix the reactance of the antenna circuit and, therefore, frees the secondary from the effects of the antenna capacity. A second difficulty with this circuit is that

the step-up from the antenna to the grid of the first tube increases with the frequency; *i.e.*, with this type of coupling, h-f stations will be amplified much more than the l-f stations. This condition is aggravated by the use of similar couplings in the interstage transformers. The amplification over the broadcast band can be equalized to some extent by using the circuit shown in Fig. 81.

Band-pass Circuits.—Band-pass circuits consist of a series of tuned circuits that allow only a limited band of frequencies to pass. These circuits are used to obtain a tuning curve that will not be so narrow that the higher audio frequencies are cut off and at the same time will have a sharp cut-off giving high selectivity. In order to understand the reason for this, it is necessary

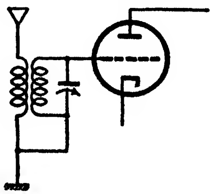


FIG. 80.—Circuit diagram of obsolete antenna connections.

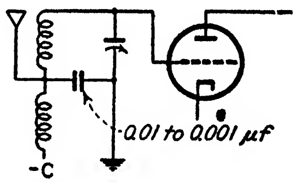


FIG. 81.—Circuit diagram of more modern antenna connections.

to know something of the nature of the signal radiated by a broadcasting station. When a station is turned on but there is no sound going into the microphone, the station radiates a single frequency. If a single frequency such as 400 cycles entered the microphone, the station would then radiate three frequencies, namely, the original or carrier frequency and two side-band frequencies, one 400 cycles above the carrier and one 400 cycles below it. For any frequency other than 400 cycles the same thing would happen. If an orchestra is playing a large number of notes simultaneously, with each note having a number of harmonics, it can be seen that the station will radiate practically all the frequencies between the carrier frequency minus the highest harmonic played and the carrier frequency plus the highest harmonic played. For a station assigned to 1,200 kc. that would mean a band from 1,195 to 1,205 kc. If high-fidelity reception is to be attained, all these frequencies must be received equally well.

Figure 82 shows the results obtained with a simple tuned circuit such as that in Fig. 80. It shows that the low frequencies

that would be near the carrier frequency will be received very much better than the higher frequencies. A 5,000-cycle note would be received somewhat less than half as well as a low note. Figure 83 shows the results that can be achieved with band-pass

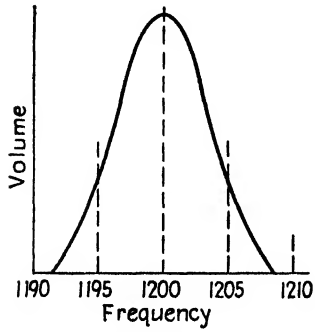


FIG. 82.—Frequency-vs.-volume characteristic of a simple tuned circuit.

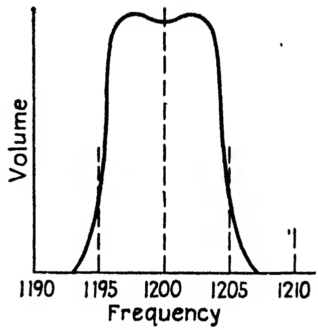


FIG. 83.—Frequency-vs.-volume characteristic of a band-pass circuit.

circuits. Note that nearly all the frequencies are received equally well.

Figure 84 gives the schematic circuit for a band-pass circuit using inductive coupling. The tuned circuit L_1, C_1 is a wave trap and is usually tuned to the intermediate frequency. Each of

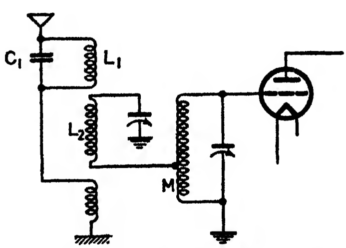


FIG. 84.—Circuit diagram of inductively coupled band-pass circuit.

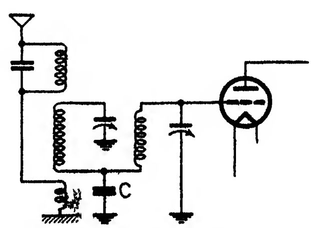


FIG. 85.—Circuit diagram of a capacitively coupled band-pass circuit.

the two tuned circuits with the variable condensers contains the portion of the coil marked M, which is the coupling medium between the circuits. This type of coupling gives poorer selectivity at the higher frequencies. Low response at frequencies below 1,000 kc. with this circuit might be caused by C_1 being

open or of too high capacity or by too loose coupling between L_1 and L_2.

Figure 85 gives the schematic diagram of a band-pass circuit using capacitive coupling. Both of the tuned circuits contain the condenser C, which is the coupling medium in this circuit. The selectivity of this circuit improves as the frequency increases.

Figure 86 gives the schematic diagram of a band-pass circuit using both inductive and capacitive coupling. In this circuit, both M and C are part of each tuned circuit. The selectivity of this circuit is practically uniform all over the broadcast band if it is properly designed. Many of the midget sets have a modification of this circuit as shown schematically in Fig. 87. The upper open-circuited coil of a very few turns acts as a condenser and gives the necessary capacitive coupling to improve the selectivity at high frequencies. Lack of sensitivity at high frequencies in these sets may be due to too low capacity between this coil and the tuning coil.

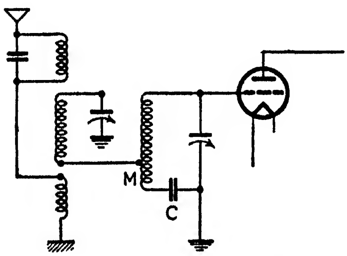


FIG. 86.—Circuit diagram of combined inductive and capacitive coupling in a band-pass circuit.

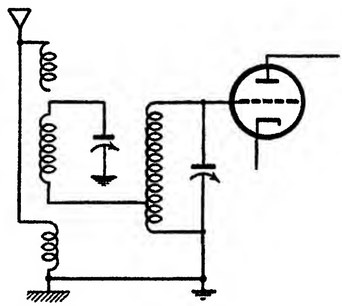


FIG. 87.—Circuit diagram of a modification of the band-pass circuit.

The modern r-f transformers have honeycomb-coil primaries of high inductance, which are tuned to a frequency below the broadcast band by their distributed capacity and other tube and circuit capacities; or a smaller coil may be used, shunted by a condenser, to achieve the same result. By the use of these primaries, the selectivity and amplification can be approximately equalized over the whole broadcast band.

Shielding.—It has already been shown that all wires carrying current are surrounded by a magnetic field and that the field

about a coil is very strong. When high-gain tubes are used, the slightest feedback from the plate circuit to the grid circuit results in oscillation. To prevent this difficulty, shields are used to separate the various circuits. However, shields also introduce some undesirable features. The theory of shielding states that currents (called "eddy currents") which are generated in the shields have just the opposite magnetic effect from that of the current in the coils; thus, the magnetic field of the coil is neutralized by that of the shield. The eddy currents are generated in the shields exactly as the current is generated in the secondary of a transformer, and, like the current in the secondary of a transformer, they absorb energy from the primary, which, in the case of the r-f coils, is the radio circuit. The result is the same as adding resistance to the radio circuit, which always broadens the tuning and reduces the volume. For this reason, shielding should be used only where necessary. It should not be too close to the coils, or excessive losses will be experienced.

For audio frequencies, magnetic material is best for shielding. It should have sufficient thickness to carry the required flux easily. For the higher frequencies, materials having a high electrical conductivity, such as copper and aluminum, are best.

Loose shield cans have been found to be the source of many annoying and puzzling difficulties in radio sets. They may cause howling, intermittent noises, staticlike noises, and many other peculiarities. Shielding that has high-resistance joints in it may give more trouble than no shields at all.

Always be sure that all the shields are in place when a set is being neutralized or the condensers equalized, because the presence of the shielding has a very noticeable effect on the balance and the tuning of the set.

REVIEW QUESTIONS

5-1. Give two advantages of r-f amplifiers over a-f amplifiers.

5-2. Explain the cause of oscillation in r-f amplifiers.

5-3. Show a diagram for preventing oscillation in r-f amplifiers using triode tubes.

5-4. Explain another method of preventing oscillation.

5-5. What is a band-pass circuit?

5-6. What advantage does a band-pass circuit have?

5-7. Show a diagram for an inductively coupled band pass.

5-8. What are the selectivity characteristics of an inductively coupled band-pass circuit?

5-9. Show a diagram for a capacitively coupled band pass.

5-10. What are the selectivity characteristics of a capacitively coupled band-pass circuit?

5-11. Show a diagram of a combined inductive and capacitive coupling in a band-pass circuit.

5-12. What are the selectivity characteristics of a band-pass circuit having both inductive and capacitive coupling?

5-13. What is the purpose of shielding?

5-14. What disadvantages, if any, has shielding?

5-15. Explain the theory of shielding.

5-16. What type of materials is suitable for r-f shielding? Name three suitable materials.

5-17. What type of materials is suitable for a-f shielding? Name two suitable materials.

5-18. What precautions are necessary in regard to shields when aligning a set?

CHAPTER VI

THEORY OF AUDIO-FREQUENCY AMPLIFIERS

Amplifier Characteristics.—If an amplifier is to be satisfactory for a particular installation, it must be adaptable to the work for which it is intended. For instance, an amplifier that is to be used on a truck with storage batteries as the only source of power must use a minimum amount of power. Sometimes the space that an amplifier can occupy is limited; in this case, tubes with high amplification factors and circuits are essential. For the average public-address work, high gain and medium power with reasonably good quality are necessary. Audio amplifiers used in broadcast studios must have very high fidelity with space and power requirements of secondary importance. Some of the characteristics that any amplifier should possess are as follows:

1. *It must be free from frequency distortion.* This means that it must amplify equally all frequencies in its range. The lower limit of the average amplifier is usually between 50 and 100 cycles with the upper limit from 5,000 to 7,000 cycles.

This type of distortion is due largely to the coupling devices used between the tubes, although the tube characteristics, *e.g.*, the input capacitance, are partly responsible. High-fidelity amplifiers are now built with a frequency range of 30 to 15,000 cycles, but considerable difficulty is experienced with noise due to static from the r-f amplifier or scratch from the phonograph records, as well as hiss and other tube noises. Furthermore, it is impossible to receive audio frequencies above 5,000 cycles by radio without interference from stations on adjacent channels if the receiver is sensitive enough to pick them up.

2. *It must be free from amplitude distortion.* This type of distortion occurs when the output is not exactly proportional to the input. The conditions under which the tubes are operating are primarily responsible for this type of distortion. The selection of the proper C bias, plate voltage, and load impedance will keep this type of distortion at a minimum. This type of distor-

tion introduces frequencies in the output that were not present in the input. These frequencies will be harmonics of the frequencies present in the input. The introduction of these frequencies is very apparent to the ear and is responsible for practically all the distortion noticeable to the human ear.

3. *It must be free from excessive phase distortion.* This type of distortion is of very little importance except in television receivers. It is caused by characteristics of the amplifier that cause some frequencies to pass through the amplifier more rapidly than others and are therefore misplaced in the output. The ear is very insensitive to this type of distortion but it will cause very apparent distortion in a television image.

4. *It must be free from oscillation (howling) and tube noise.* If it is an a-c amplifier, it must be free from hum.

5. *It must be capable of handling the required amount of power without overloading.*

6. *Its input and output circuits must be designed to work satisfactorily with the devices connected to it.*

The causes and remedies for these types of distortion will be considered more fully in connection with the various types of amplifiers.

Types of Amplifiers.—There are three types of amplifiers based on the method of operation. These are known as Classes A, B, and C. A fourth class known as A′, or AB, is a hybrid of Classes A and B.

A Class A amplifier is one in which the *C* bias is of such a value that the operating point lies in the center of the straight portion of the E_gI_p curve on the negative side of the zero grid-voltage line as shown in Fig. 28. If the signal is so large that it swings the grid to a positive value, it will attract electrons from the cathode and grid current will flow. Since the circuit connected to the grid of the tube does not normally carry current, it is designed with very high impedance to increase the gain and improve the quality. However, if grid current is allowed to flow, the very high impedance in this circuit will cause a large voltage loss during the portions of the cycle in which grid current flows. This of course alters the voltage applied to the grid and results in serious distortion. The same effect is produced with a normal value of signal voltage if the *C* bias is too low. An excessive signal will also usually swing the grid to such a high negative

value that the lower curved portion of the characteristic is encountered. This results in detector action, which is distortion of the lower loops of the plate-current curve. Practically the same effect is produced by using too high a negative bias on the control grid. In no case should the *C* bias be any greater than is required to keep the grid from going positive. Any increase over this value will result in a lower output.

There are two varieties of Class AB amplifiers. The first type, known as the AB_1, has a *C* bias that is just a little higher than that for Class A. It therefore operates as a Class A amplifier for small signals with excellent quality. As the signal increases,

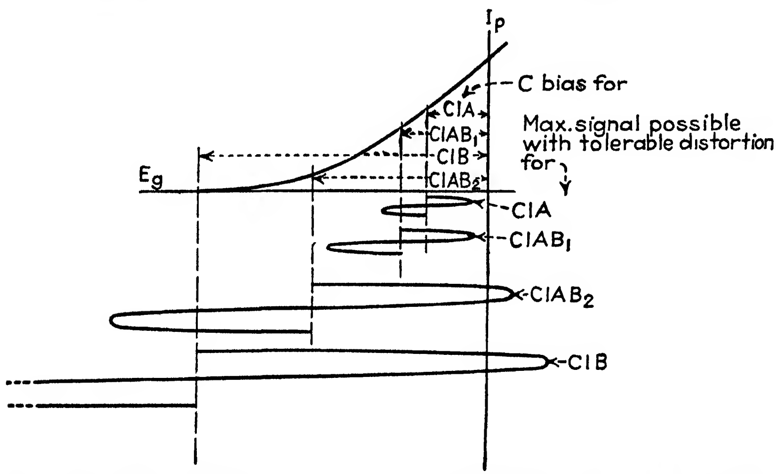


FIG. 88.—Chart showing the operating conditions for all classes of audio amplifiers.

the bias is increased automatically (owing to the operation of the *C* bias resistor), and a larger signal can be used without the grids going positive. No grid current flows in a Class AB_1 amplifier. The second type, known as the AB_2, has a *C* bias that is a little lower than that of a Class B amplifier. A larger grid signal can be used, but the quality will not be quite so good as in the two preceding amplifiers. Grid current flows during part of each cycle in this amplifier, and suitable precautions (discussed under "Push-pull Amplifiers") must be taken to prevent this from producing so much distortion that the amplifier is useless.

Class B amplifiers have a *C* bias that holds the plate current at cut-off when no signal is present. They will be discussed more

fully under "Push-pull Amplifiers" because, except in transmitters, these amplifiers can be used only in push-pull circuits.

Class C operation is not practical except in certain r-f amplifiers used in transmitters. In these amplifiers, the *C* bias is so large that the plate current is beyond cut-off when no signal is present. Figure 88 illustrates the operating conditions for the various types of amplifiers.

Amplifiers are also classified by the type of coupling used between the tubes. Under this classification there are:

1. Transformer-coupled amplifiers.
2. Resistance-coupled amplifiers.
3. Direct-coupled amplifiers.
4. Impedance-coupled amplifiers.

Transformer-coupled Audio Amplifiers.—The circuit of a transformer-coupled audio amplifier using both filament- and

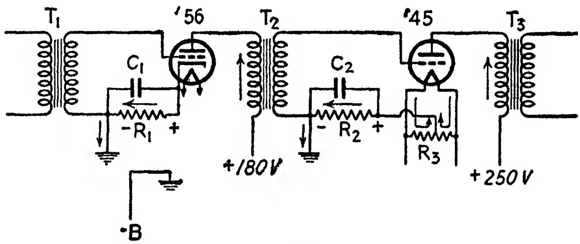


FIG. 89.—Circuit diagram of a transformer-coupled audio amplifier.

heater-type tubes is given in Fig. 89. The plate currents of the tubes (indicated by arrows) pass through the resistors R_1 and R_2. The *IR* drop produced by this current in these resistors provides the necessary *C* bias. The method of determining the value of these resistors was explained in Chap. I, page 12.

Degeneration.—The condensers C_1 and C_2 prevent degeneration or loss of volume in the following manner: When the phase of the signal is such that it is making the grid less negative, the plate current will be above the no-signal value. This additional current flowing through the bias resistor causes a higher *IR* drop resulting in a higher negative bias, which offsets the decrease in the bias due to the signal. During the other half cycle of the signal voltage when the signal is making the grid more negative, the plate current will be below the no-signal value, and this current flowing through the bias resistor will give a lower bias,

which again opposes the signal voltage. This action will reduce the gain of the amplifier to a very low value. This difficulty can be overcome by placing across the bias resistor a condenser so large that the plate current cannot charge it during a half cycle of the signal at the lowest frequency desired. This condenser acts in the same manner that a large air tank would on an air pipe line. In the air-pressure system shown in Fig. 90, if the pressure was

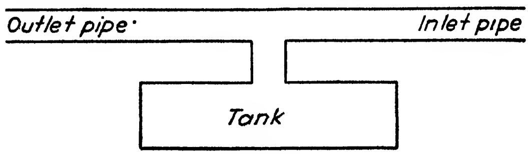


FIG. 90.

suddenly increased at the inlet, the pressure at the outlet would not increase until the pressure in the tank had also increased. If the increase in the pressure on the inlet was maintained for only a very short time and then released, it would have practically no effect on the outlet pressure. In the same manner, a large condenser across the *C* bias resistor will prevent any change in the electrical pressure across the resistor unless it is charged to that potential. Lower frequencies take more time to complete one cycle. Therefore they require that the condenser be larger than for the higher frequencies; otherwise the condenser will be fully charged at the lower frequencies, and degeneration will result at these frequencies.

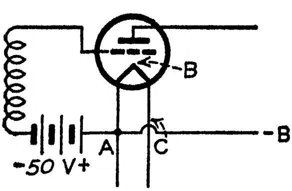


FIG. 91.—Circuit diagram showing *C* bias returns with d-c filaments.

Grid Returns.—In a d-c set, the grid return is connected to one side, usually the negative, of the filament, and this connection works out very successfully because this end of the filament has a constant potential. In the case of an a-c filament, this connection is not satisfactory because during one half cycle it is positive and for the next half cycle it is negative. This condition has the effect of rapidly changing the *C* bias, as shown in Fig. 91. Take a 45 tube, for example, which requires 2.5 volts alternating current on the filament. For one half cycle, the point *A* is 2.5 volts above *C*; and for the other half cycle, it is 2.5 volts below *C* or 1.25 above or below point *B*, the middle of the fila-

ment. Now compute the grid bias. There is a constant bias of 50 volts owing to the battery, but when A is 1.25 volts below B, the total bias is 50 plus 1.25, or 51.25. When A is 1.25 volts above B, the bias is 50 minus 1.25, or 48.75 volts. In other words, the bias is varying from 48.75 to 51.25 volts, a change of 2.5 volts, and a change of grid bias always changes the plate current. The result is a very bad a-c hum in the loud-speaker. This hum can be reduced a great deal by connecting across the filament leads a resistance whose value in ohms is about ten times the voltage of the filament. For instance, in the preceding example, a 20- to 25-ohm resistance would be sufficient.

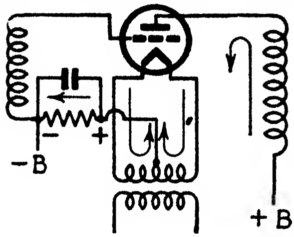


FIG. 92.—Circuit diagram showing C bias returns with a-c filaments.

The grid return and the minus B return are then connected to the middle tap on this resistance as shown with the type 45 tube in Fig. 89. Sometimes a potentiometer is used to get a fine adjustment of the electrical center. Another method that gives the same results is to bring the grid return to the center of the secondary that feeds the filament, as shown in Fig. 92. Some sets

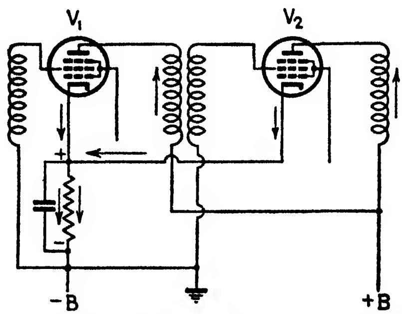


FIG. 93.—Circuit diagram showing common C bias resistor.

use a common C bias resistor for a number of similar tubes as shown in Fig. 93. This circuit is practical only with tubes having very small fluctuations in the plate circuit, such as screen-grid tubes. If the plate current of V_2 varies to any great degree, it will cause the voltage across the bias resistor to vary, which will introduce a signal voltage in the grid circuit of the first tube. This signal is passed on to the second tube and causes

its plate current to vary, which again disturbs the first tube and results in a continuous oscillation. When the plate-current variations are small, the by-pass condenser across the bias resistor can smooth out the voltage fluctuations and, therefore, prevent this action. In some sets, the field coil of the dynamic speaker is connected between ground and the midtap of the high-voltage secondary, and either all or part of the voltage drop is used for C bias. The circuits for some of the variations of this scheme are shown in Fig. 94. Part (*a*) shows the general circuit. It will be noticed that the grids of V_1 and V_2 are at ground poten-

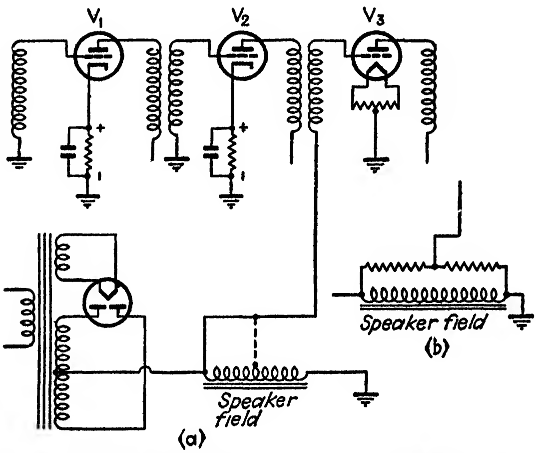


FIG. 94.—Circuit diagram showing common C bias arrangements.

tial; however, the cathodes are the required amount positive to ground, thus providing the proper C bias. In the case of V_3, the filament is at ground potential but the grid is connected to a point that is negative in respect to ground. When the voltage drop across the whole field is too high, a tap may be used as shown by the dotted line in (*a*) or a voltage divider may be used as shown at (*b*).

Audio Amplification with Power Pentodes.—The only advantage that power pentodes have over other tubes is their ability to deliver large amounts of power with small signal-voltage input. Because of this advantage, they are particularly useful in midget and automotive sets. However, the increased volume is accompanied with greater distortion. To minimize this distortion, the plate load must have the effect of a resistance. Since these

tubes are output tubes, the use of an output transformer cannot be avoided, which without compensation is an inductive load and would produce high distortion. To avoid this difficulty, a filter network consisting of resistances and condensers is usually connected across the primary. These tubes are very critical as to the value of the plate load for minimum distortion.

Push-pull Amplifiers.—There are two main classes of push-pull amplifiers used in audio amplification. Class A amplifiers use a grid bias such that the tubes are working on the straight portions of their characteristic curves. They have relatively low output with high fidelity. Class B amplifiers use a grid bias that reduces the plate current to zero, or very nearly so, with no signal present. These amplifiers have relatively high output, but their fidelity is inferior to that of Class A. The circuit for both classes is shown in Fig. 95. Several tubes have been developed for Class B operation, in which the cut-off point is very close to zero bias. When these tubes are used, the grid-bias resistor R is not necessary. Usually a bias resistor by-pass condenser is not used on a push-pull stage. It is not necessary because the combined plate current of the two tubes which flows through it is essentially constant. From an inspection of the diagram in Fig. 95, it can be seen that as the grid bias on one tube is increasing, that on the other is decreasing. This causes the plate current of the first tube to decrease and that of the second tube to increase; therefore, the combined plate current of the two tubes remains constant, and a by-pass condenser is not necessary. Where very high quality is desired, a by-pass condenser is required because of current fluctuations due to mismatched tubes and to odd harmonics that are not canceled.

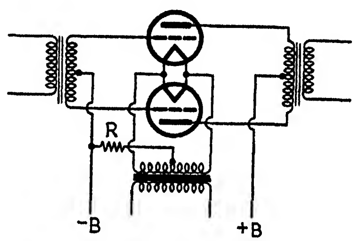


FIG. 95.—Circuit diagram of a push-pull audio amplifier.

In a Class A push-pull stage, the two tubes produce approximately the same power as three tubes in parallel. In a Class B stage, the increase in the power output is even greater. The push-pull circuit balances out all even harmonic distortion and also any hum that may get through the B power-supply filters. This means that the plate current used by the push-pull stage

requires much less filtering than that of the other stages. In fact, sets have been on the market in which the plate supply for the push-pull stage was tapped off the filament of the rectifier, the only filtering being the condenser at the input to the filter. However, a very bad hum results with this connection unless the two tubes have identical characteristics. Such tubes are hard to find and impossible to maintain in that condition.

In a Class A stage, the plate currents of the two tubes flow through the primary of the output transformer in opposite directions so that the magnetism caused by the current of one tube is neutralized by that of the other. This means that small cores can be used and still maintain high quality. In Class B amplifiers, only one tube draws current at a time, and so the magnetism of one cannot neutralize that of the other and larger cores are necessary.

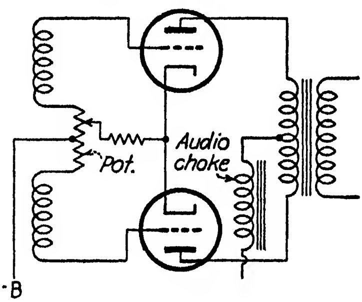


FIG. 96.—Circuit diagram showing method of equalizing the plate currents of push-pull tubes.

By putting two tubes in parallel on each side of the push-pull connection, four times the power with two tubes may be obtained. Paralleling the plate circuits of the two tubes halves their plate impedance and also doubles the current flowing in the primary of the output transformer so that an entirely different output transformer will be required for this circuit than that used for the push-pull connection.

Push-pull amplifiers sometimes howl, owing to parasitic oscillations. The remedy for this condition is a resistor of from 25,000 to 100,000 ohms inserted in the grid circuit at the center tap of the input transformer.

Some of the high-powered push-pull amplifiers use the connection shown in Fig. 96 to vary the *C* bias on the individual tubes to equalize the plate currents. This removes core saturation in the output transformer, as explained previously. With the potentiometer arm, as shown, the lower tube has a higher bias than the upper one.

High-quality push-pull amplifiers often have an audio choke in the plate circuit, as shown in Fig. 96.

The direct current in the plate circuit of a Class A push-pull amplifier should not fluctuate. If this current varies with the signal, it indicates overloading of the power stage.

Push-pull amplifiers that are designed to amplify up to 10,000 cycles or above sometimes oscillate at the higher frequencies. This can be prevented by neutralizing them. The schematic circuit for this purpose is shown in Fig. 97. The condensers C_1 and C_2 have a capacity slightly larger than the plate-to-grid capacity of the tubes.

Neutralizing Procedure.—To neutralize a push-pull audio amplifier, proceed as follows:

1. Disconnect the plate supply at A, Fig. 97.
2. Open the plate circuit of one of the tubes as at X.
3. Connect a pair of phones across the secondary of the output transformer and adjust the condenser C_1 until a minimum sound is heard. During this operation, a normal signal should be fed into the stage.
4. Reconnect the plate of the tube at X and repeat the operation with the other tube.
5. Reconnect the B supply at A. If the oscillation still persists, a slight adjustment of the condensers will eliminate it.

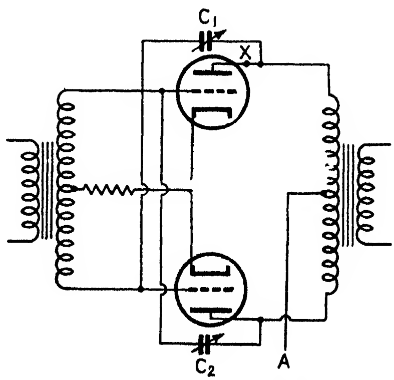


FIG. 97.—Diagram of a neutralizing circuit for push-pull tubes.

Class B Push-pull Amplifiers.—To meet the demand for higher power output with reasonable plate voltage and small tubes, the Class B amplifier was developed.

In Class A amplifiers, the tubes are biased so that they operate on the straight portion of the E_gI_p curve, and they both operate during the entire cycle of the signal voltage. If the signal is so large that it forces the grid beyond the cut-off point or to a positive potential, serious distortion results. Tubes designed to be used with Class B amplifiers have their plate cut-off very close to zero grid bias. In this group of tubes are 6A6, 6N7, 6N7G, 19, 46, 49, 53, 59, 79, and 89. Each tube operates only during one half of the signal voltage cycle.

The operation of a Class B stage can be explained by referring to Fig. 98. The E_gI_p curves of the two tubes are drawn, one being upside down from the usual position because it is connected in opposition to the other tube and its action can best be shown by making the diagram in this manner. Since there is no C bias,

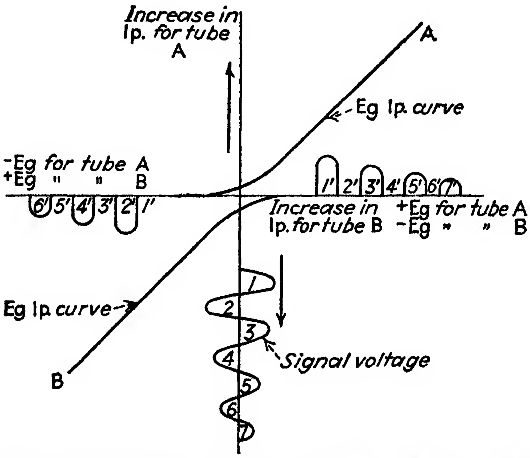


FIG. 98.—Diagram showing the operation of Class B tubes in a push-pull circuit.

the signal voltage will swing the potential of the grids each side of the zero grid-voltage line as shown. When the signal voltage swings in the direction indicated to the right in the diagram, tube A will draw plate current, as shown by the curve marked 1′, 2′, 3′, 4′, etc. At the time that tube A is drawing current, tube B is beyond its cut-off point in the negative direction and so does not draw any plate current. As the grid voltage swings in the opposite direction, the action is reversed; tube B draws current whereas tube A does not. From the shape of the plate-current curves, it is evident that the total plate current in a Class B stage is not uniform as it is in a Class A stage. The combined effects of the two plate currents flowing through the primary of the output transformer cause a current to flow in the secondary, as shown in Fig. 99.

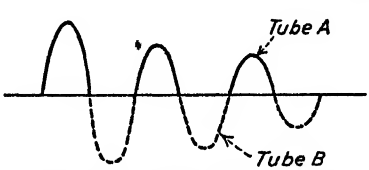


FIG. 99.—Diagram showing how the output transformer recombines the two halves of the signal cycle.

Since the grids of these tubes become positive, they draw current. The input circuit then uses power—both voltage and current—and this power must be supplied by the preceding stage, called the "driver," which, therefore, must be a power tube. The necessity of supplying current to the grids also means that the ordinary push-pull input transformer secondary cannot be used for the following reasons:

1. The fine wire used on Class A transformers to reduce the distributed capacity will not carry the current required in a Class B stage. If a larger size of wire is used, the number of turns must be reduced or the distributed capacity will be excessive.

2. If the winding has high resistance and high inductance, large *IZ* drop will be created every time the grids draw current. This means that the signal voltage applied to the grids will be reduced during that portion of the cycle in which the grid draws current. The distortion of the signal voltage, of course, results in distortion in the output of the loud-speaker. To overcome this difficulty, the number of turns is reduced. This reduces the inductance and also the length of the wire used, which in turn decreases the resistance.

3. Since the grids of the tubes draw current, they have a relatively low input impedance. In order to match this low impedance to the plate of the driver tube, a step-down transformer is required.

It will be noticed that all these items require that the transformer be of the step-down variety.

Class B amplifiers also require a special power pack because they require that the current vary from about 10 to 200 ma. without any marked variation of output voltage. A power pack designed for a Class A amplifier will not meet these requirements for the following reasons:

1. The voltage of the power transformer varies considerably with the changing load.

2. The difference between the a-c transformer voltage and the d-c output voltage of a vacuum-tube rectifier increases as the load increases.

3. With chokes having 200 to 500 ohms resistance, the *IR* drop through them varies considerably with a variation from 10 to 200 ma.

The power transformer of a Class B amplifier power pack must be designed to maintain a nearly constant voltage over wide load variations. This condition is secured by using plenty of iron, not too many turns on the primary, and a generous-sized wire for the secondary.

The rectifier must have nearly a constant voltage drop for all loads. The 82 and 83 tubes were designed to obtain this feature.

The filter chokes must have as little resistance as possible.

Audio-transformer Characteristics.—A primary with high impedance is essential if a transformer is to amplify low frequencies, because of the following facts: The voltage developed in the secondary is directly proportional to the voltage developed across the primary. Furthermore, the only voltage that can exist across the primary is an IZ drop across its terminals. In the expression IZ, the $Z = \sqrt{R^2 + X_L^2}$. The quantity X_L varies with the frequency as shown by the formula $X_L = 2\pi fL$, which shows that X_L decreases as the frequency decreases. This reduces Z and IZ at low frequencies so that a lower voltage is applied to the primary than at high frequency, all other factors remaining unchanged. By making the inductance L of the primary large, this effect is minimized. To obtain this impedance, the primary must have a large number of turns. If the transformer is to have a high step-up ratio, say 6 or 10:1, the secondary must have six to ten times the number of turns on the primary. This makes an extremely large number of turns and, owing to this large number, another difficulty is encountered, which is known as the "distributed capacity" of the winding. The cause of this difficulty can be explained in this way: A condenser consists of two pieces of conductive material insulated or partly insulated from each other. The layers of the winding of the coil, or two adjacent turns, will act as a condenser. Hence, it can be seen that this capacity effect is distributed throughout the coil and, for this reason, is called the "distributed capacity." Another important point in the design of an audio transformer is to arrange the coils in such a way that all the magnetic lines of force generated by the current in either coil pass through the other coil. As the number of turns on the coils increases, this becomes more and more difficult to accomplish. Any magnetic lines from one coil that do not cut the other will have the same effect as an external inductance in series with the coil. This

inductance and the distributed capacity of the coil form a circuit that is usually resonant near 7,000 cycles. Since the circuit is tuned at this frequency, the amplification at and near this frequency will be much greater than at frequencies remote from it. Furthermore, the amplification above this frequency will fall off very rapidly. Therefore, a high-ratio transformer has one of two characteristics: either the primary has two few turns to pass the low notes, or the secondary has so many that the difficulty just described is encountered at high frequencies. For this reason, a satisfactory interstage transformer with a ratio much higher than 3:1 is difficult to design. Input and output transformers do not require such high impedances and can, therefore, be built with higher ratios.

A transformer having the characteristics just described can often be improved by putting a resistance across the secondary. This resistance may be from 100,000 to 500,000 ohms. The smaller the resistance, the better the quality secured, but the smaller the amplification.

It must also be remembered that the primary carries the d-c plate current which magnetizes the core and, if this current is excessive or if the core is small, it may approach magnetic saturation. This greatly reduces the permeability of the iron, with consequent reduction in the inductance of the primary. The remedy for this difficulty is to use cores of sufficient size so that normal plate current will not saturate them and then to make suitable adjustments in the amplifier so that the plate current will not be excessive. This usually is accomplished by adjusting the grid and plate voltages.

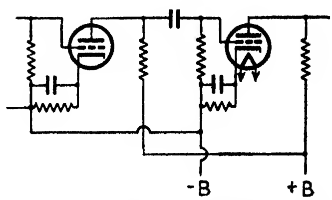


FIG. 100.—Circuit diagram of a resistance-coupled audio amplifier.

Resistance-coupled Audio Amplifiers.—A resistance-coupled amplifier is one in which the signal is passed from one tube to the next by means of the *IR* drop in resistors. A resistor is placed in the plate circuit of the first tube. The *IR* drop across this resistor is passed to the grid of the next tube. The plate voltage is prevented from reaching the grid of the tube by inserting a condenser in this circuit, which allows the a-c signal to pass through but stops the direct current. The schematic circuit of a

resistance-coupled amplifier is shown in Fig. 100. Increasing the resistance in the plate circuit would increase the signal voltage output except that it also reduces the plate voltage, which lowers the output. For triodes, the plate resistor should be approximately two or three times the plate resistance of the tube.

A second resistor should be connected between the grid and cathode of the second tube; otherwise, the condenser in the grid circuit blocks the escape of electrons from the grid. For maximum gain, this resistance should be ½ megohm or higher. Tube data should be consulted so that the maximum allowable resistance in the grid circuit of any particular tube is not exceeded, or very bad effects may result.

The amplification of a resistance-coupled amplifier is entirely in the tubes. The theoretical maximum amplification per stage is that of the tube; however, this can never be fully realized. Amplification at high frequencies drops down, owing to the input capacity of the second tube, whereas at low frequencies it drops down because of the reactance of the blocking condenser, which increases at low frequencies.

A difficulty sometimes encountered with resistance-coupled amplifiers is a staticlike noise, which is caused by using resistors with too small wattage rating. The normal tube-operating conditions for resistance coupling are not the same as for other methods of operation. For example, a 6C6 when used as a r-f amplifier draws 2-ma. plate current but when used in a resistance-coupled audio amplifier the plate current is 0.5 ma. or less. Proper conditions for tubes used in resistance-coupled amplifiers are given in the Appendix.

Direct-coupled Amplifiers.—The schematic diagram of this circuit, which became popular in 1930, is given in Fig. 101.

One of the undesirable features of the resistance-coupled amplifier is the coupling condensers, which tend to limit the l-f response. The direct-coupled amplifier, which does not use this coupling condenser, has been developed. From a study of the schematic circuit shown in Fig. 101, it can be seen that there is nothing unusual in the power supply or the voltage divider. The difference is in the method of connecting the amplifier to the power supply. A simplified circuit diagram is shown in Fig. 102. Note that the filament of tube 2 is negative in respect to its plate and that the grid is negative in respect to the filament. If the proper

resistances are used, all the voltages on this tube will be normal. The plate of tube 1 is connected directly to the grid of tube 2, but a study of the diagram will show that the grid and plate voltages of this tube in respect to its filament are normal. Figure

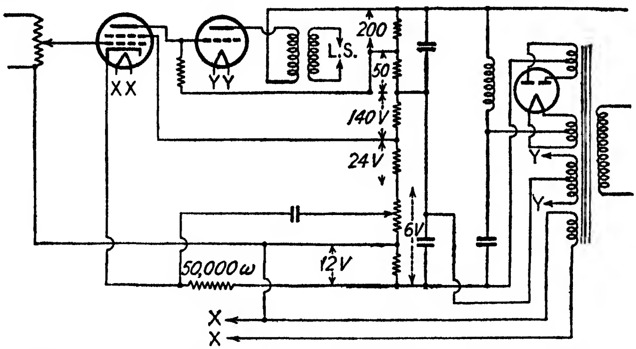


FIG. 101.—Circuit diagram of a direct-coupled audio amplifier.

103 shows the original circuit arranged to show its similarity to Fig. 102. The 0.5-megohm resistor is in series with the plate resistance of tube 1, and this series circuit is in parallel with a portion of the voltage divider. The IR drop in the 0.5-megohm

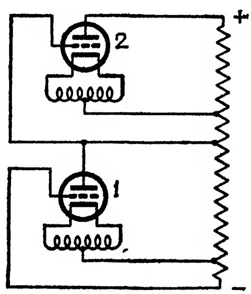


FIG. 102.—Elementary circuit diagram of a direct-coupled amplifier.

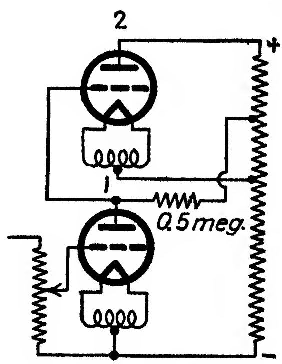


FIG. 103.—Practical circuit diagram of a direct-coupled amplifier

resistor, due to the plate current of tube 1, supplies the tube 2 with the proper negative grid bias. It, therefore, is not a good practice to remove the first tube from its socket when the amplifier is turned on for this will remove the IR drop in the 0.5-

megohm resistor and put a positive voltage on the grid of the output tube. The increase in its plate current may damage the output transformer or the tube or both.

Direct-coupled amplifiers are also used to amplify the feeble direct current produced by a photoelectric cell. The photoelectric-cell output is passed through a resistor, usually of 10 megohms or more, in the grid circuit of the first tube of the amplifier. The *IR* drop due to this current increases the bias on the first tube, which reduces its plate current. This reduction decreases the *IR* drop in the 0.5-megohm coupling resistor (see Fig. 103), which decreases the bias on the output tube and increases its plate current. Thus the few microamperes output of the photoelectric cell may cause a 10- or 15-ma. change in the plate current of the output tube. This is ample variation to ensure positive operation of a relay capable of handling considerable power.

All other types of amplifiers cannot amplify direct current in this manner. They require a pulsating or an alternating signal input. For this reason, direct-coupled amplifiers are used extensively in the application of electron tubes to industrial control.

Impedance-coupled Amplifiers.—It is possible to substitute audio impedances for the plate and grid resistances in a resistance-coupled amplifier. The resulting circuit is known as an "impedance-coupled amplifier." The choke in the plate circuit has less d-c resistance, which results in a lower plate voltage loss. However, since the impedance of the choke decreases as the frequency is lowered, the l-f response of this amplifier will be inferior to that of the resistance-coupled amplifier. The impedance in the grid circuit has one good feature due to its lower resistance, *viz.*, that the amplifier will not produce distortion due to the grids of the tubes blocking on strong signals. The lowered impedance of the grid choke at low frequencies has a tendency to by-pass these frequencies, which still further reduces the l-f response. For the preceding reasons, the impedance-coupled amplifier is little used.

Inverse Feed-back Amplifiers.—Many modern amplifiers owe their excellent high-fidelity characteristics to inverse feed-back circuits which are practical in modern amplifiers because of the development of high-mu voltage amplifier tubes and high-power output tubes. The increase in the quality obtained by using inverse feed-back circuits is obtained at the expense of amplifica-

tion and power output and was not practical until a surplus of these quantities could be obtained.

In inverse feed-back circuits, a certain percentage of the output is fed back into one of the preceding stages so that it will cancel out a portion of the incoming signal at this point. The amount

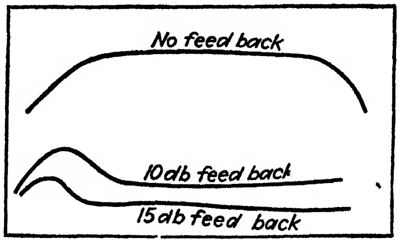


FIG. 104.—Chart showing the effect of inverse feedback on the frequency characteristics of an amplifier.

of any particular frequency that will be canceled out depends on the amount of that frequency present in the output. Thus, if an amplifier overamplifies the higher frequencies, a greater amount of these frequencies would be fed back and would cancel out more of the incoming signal. Thus the effective signal of any frequency at the point of feedback is reduced in proportion to the amount of that frequency present in the output. Figure 104

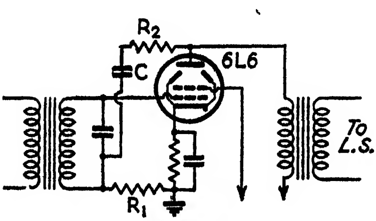


FIG. 105.—Circuit diagram of inverse feedback circuit for a 6L6 only.

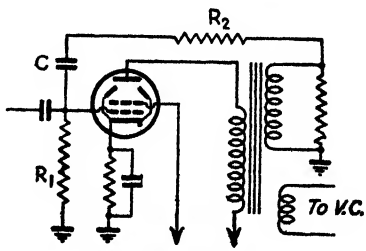


FIG. 106.—Circuit diagram of inverse feedback circuit for a 6L6 and the output transformer.

shows how the amplification of an amplifier at various frequencies is more nearly equalized by the various percentages of feedback.

An inverse feed-back circuit for a single tube is shown in Fig. 105. This circuit is often used to neutralize the high harmonic distortion of a single 6L6 tube. Since the feed-back circuit does not include the input and output transformers of the stage,

any distortion caused by them will not be reduced. The distortion due to the output transformer is reduced by the circuit shown in Fig. 106. A coil having higher impedance than that of the output transformer secondary is required to produce sufficient voltage for feed-back purposes.

The number of stages included in the feed-back circuit is limited by the phase shift in the amplifier. Two stages give very little difficulty, but three stages can be used only by reducing the phase shift to a minimum. The application of inverse feedback to three stages is shown in Fig. 107.

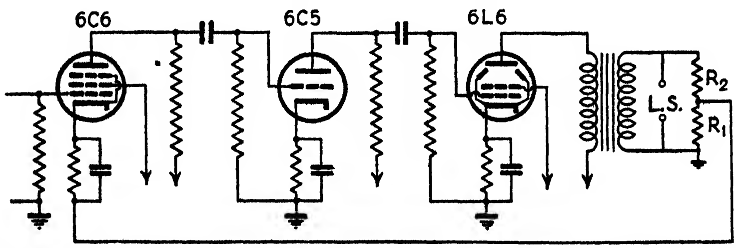


FIG. 107.—Circuit diagram of inverse feed-back circuit for a three-stage amplifier.

The percentage of feedback in all the diagrams shown will be $\frac{R_1}{R_1 + R_2}$ provided that the impedance of the blocking condensers C in Figs. 105 and 106 is small in comparison with $R_1 + R_2$.

The frequency characteristic of an amplifier can be controlled by connecting frequency-discriminating circuits across the resistor R_1. For instance, if R_1 is by-passed with a small condenser, none of the higher frequencies can build up voltage across the resistor, and, since no h-f voltage is fed back, there will be no reduction in the amplification of the high frequencies. By putting a variable resistor in series with the condenser, the amount of this effect can be controlled. Similarly, by using an impedance coil and a variable resistor, the amplification at low frequencies can be controlled.

Notes on the Design and Construction of Audio Amplifiers.—In building an audio amplifier, the following precautions should be taken to avoid hum:

1. The power pack, if mounted on amplifier chassis, should be placed near the output end of the amplifier rather than near the input for the following reason: If a slight hum is picked up by

REVIEW QUESTIONS

6-1. Name three types of audio distortion.

6-2. Name four classes of amplifiers based on the method of operation.

6-3. Define a Class A1 amplifier.

6-4. What are the main characteristics of a Class A1 amplifier?

6-5. For what purposes would a Class A1 amplifier be used?

6-6. Define a Class AB1 amplifier.

6-7. What are the main characteristics of a Class AB1 amplifier?

6-8. For what purposes is a Class AB1 amplifier used?

6-9. What are the differences between a Class AB2 amplifier and a Class B amplifier?

6-10. What advantage does a Class B amplifier have over other types?

6-11. Explain the differences between the Class A and AB1 amplifiers on one side and the Class AB2 and Class B on the other.

6-12. Explain the difference between the input transformers used for Class A and Class B amplifiers.

6-13. To what type of service are Class B amplifiers particularly adapted?

6-14. Show a diagram of a transformer-coupled amplifier.

6-15. Why are triodes always used in transformer-coupled amplifiers?

6-16. What is the purpose of the cathode by-pass condenser? Describe its action.

6-17. Why should the filament circuit of tubes without cathodes be center-tapped?

6-18. Show a diagram of a circuit for obtaining the *C* bias on a tube by a method other than a cathode resistor.

6-19. Show a diagram of a single-tube stage followed by a push-pull Class A stage.

6-20. Show a diagram of a driver stage followed by a Class B push-pull stage.

6-21. Show a diagram for equalizing the plate currents of a push-pull stage.

6-22. Show a diagram of a resistance-coupled amplifier circuit.

6-23. Show at least an elementary diagram of a direct-coupled amplifier circuit.

6-24. What happens if the first tube of a direct-coupled amplifier is removed from the socket with the power turned on?

6-25. What special advantage has a direct-coupled amplifier over all other types?

6-26. Show a diagram of an impedance-coupled amplifier.

6-27. Explain the theory of inverse feedback as applied to a-f amplifiers.

6-28. Show a diagram of an inverse feed-back circuit which includes a 6L6 and an output transformer.

6-29. Name five points to be considered in the layout and construction of an audio amplifier.

6-30. Explain the cause of motorboating.

6-31. Describe the steps that are necessary to stop a case of motorboating.

6-32. Explain why the insulation resistance of the grid blocking condenser in a resistance-coupled amplifier must be so high.

CHAPTER VII

POWER SUPPLIES

Alternating-current Power Supplies.—A power supply utilizing alternating current consists of the following main parts:

1. *Power Transformer.*—The primary of this transformer often has taps for 105, 110, 115, and 120 volts.

There are usually several secondaries; one supplies the high voltage for plate supply, a second supplies the filament of the rectifier tube, and one or more secondaries supply the filament and heater needs of the rest of the set.

2. *Rectifier.*—The high-voltage winding of the transformer is connected to the plate of the rectifier. In this tube, use is made of the fact that current can flow between the filament and plate

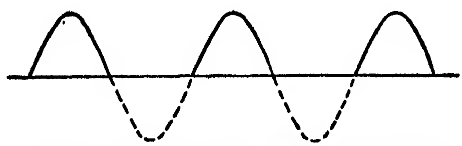


FIG. 115.—Current-output characteristic of a half-wave rectifier.

only when the plate is positive. There are two main types of rectifiers: full-wave and half-wave. The half-wave rectifier acts like a valve that shuts off the current every time it tries to go in the wrong direction. The full-wave rectifier, instead of shutting off the current in the wrong direction, reverses it and allows it to flow in the correct direction. The maximum voltage that the tube can stop flowing in the wrong direction is called the "maximum-peak-inverse voltage." The 12Z3, 35Z3LT, 35Z4GT, 35Z5GT, 45Z3, 45Z5GT, and 866 tubes are half-wave rectifiers. The 80, 82, 83, 84, 5Z3, 5Z4, and 6X5 tubes are full-wave rectifiers. The 25Z5 and 25Z6 tubes are used either way.

The half-wave rectifier changes the supply current, as shown by the solid line in Fig. 115. The output current always flows in the same direction, but it is far from being steady in value. Note that only half of the current is used. The dotted portions of the figure show the portion of the current that is not used.

The full-wave rectifier changes the supply, as shown in Fig. 116. Note that all the current is used. The dotted portion of the figure again indicates the portion of the original whose direction is changed by the rectifier. The bridge-type full-wave rectifier does not require the center-tapped high-voltage winding, but it does require four rectifiers instead of the two required when a center-tapped transformer winding is used. A copper oxide or

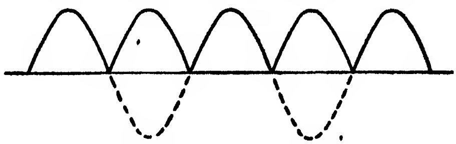


FIG. 116.—Current-output characteristic of a full-wave rectifier.

similar rectifier is generally used in this circuit, because three separate filament windings would be necessary if thermionic rectifiers were used and these windings would have to be insulated for the high voltage. Two circuit diagrams of bridge rectifiers are shown in Fig. 117. In both figures, the arrowheads point in the direction of the current flow. The connection marked *A* is usually made through the assembly bolt. This circuit is

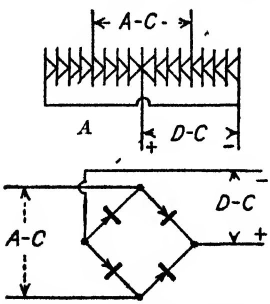


FIG. 117.—Circuit diagram of a copper oxide rectifier.

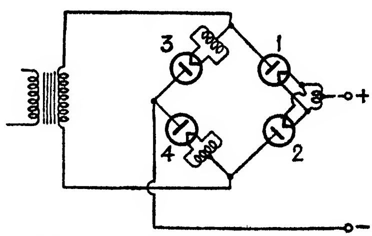


FIG. 118.—Circuit diagram of a bridge-type rectifier using electron-tube rectifiers.

extensively used to measure a-c volts or milliamperes with d-c instruments.

The circuit of a bridge-type rectifier using tube rectifiers is shown in Fig. 118. With this type of rectifier, full-wave rectification may be obtained and at the same time practically the same voltage that would ordinarily be obtained with half-wave rectification. However, it requires three filament windings instead

of only one for the conventional full-wave rectifier and at least three rectifier tubes. The two tubes indicated at 1 and 2 may be the two plates in any of the full-wave rectifiers. If the same type of tube is used for the other sides of the rectifier, only one plate of each should be used in order to keep the circuit balanced.

3. *Filter.*—The purpose of the filter is to smooth out the pulsations in the current delivered to it by the rectifier. Most of the filters used in radio sets are of the "brute-force" type. They consist of one or more chokes in series with the line and two or three condensers across the line. Filters are classified as "condenser" or "choke input" depending on whether or not there is a condenser across the line at the input. The presence or absence of this condenser has a marked effect on the characteristics of the power supply. When the condenser is present, the transformer and the rectifier must supply at least two to three times the current used by the set. This additional current is the charging current of the condenser. The d-c output voltage of the filter with a condenser input is nearly as high as the peak a-c voltage input to the rectifier. For this reason, the d-c voltage may be higher than the a-c input voltage as indicated on a voltmeter. The output voltage with choke input is a little over half the peak a-c voltage; however, the input current is not over one and a half times the current used by the set. The regulation of the choke-input filter is much superior to that of the condenser input; *i.e.*, the voltage of a choke-input filter does not drop so much when a load is put on the power supply.

In most of the radio sets using a limited number of low drain tubes, the filter chokes have been replaced by resistors having in the neighborhood of 1,500 ohms resistance. Sets requiring more current will have lower resistance values. The use of these resistors in place of chokes has many advantages, namely, cost, space required, and the fact that the resistors do not have the strong magnetic field about them, which in the case of chokes often causes a bad hum in the output.

4. *Voltage Divider.*—A resistance, known as the "voltage divider," may be placed across the line at the output of the filter from which the voltages below the highest may be obtained by means of taps, at the proper points. The voltage divider may be a single-tapped resistor, or it may consist of a number of resistors connected in series. The method of determining the

value of these resistors is shown in this chapter under "Design of Power Supply." The extra current used by the voltage divider requires that the chokes and the rectifier be large enough to carry it and, therefore, adds to the expense and to the size and weight of the power supply.

In addition to this, all the current used by the set is filtered the same amount, which is not necessary. The detector requires

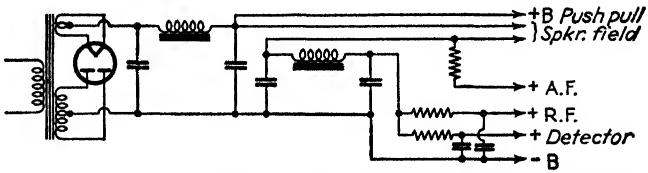


FIG. 119.—Circuit diagram of a full-wave rectifier power supply.

the highest degree of filtering, followed by the r-f amplifier; but the total current used by these components is small when compared with the current requirements of the audio amplifier. A push-pull stage, particularly, requires very little filtering. These conditions have led to the development of a power-supply circuit, which supplies properly filtered current to each part of the set. No "bleeder resistance" (another term for voltage divider) is used, which lessens the drain on the filter and in some cases may

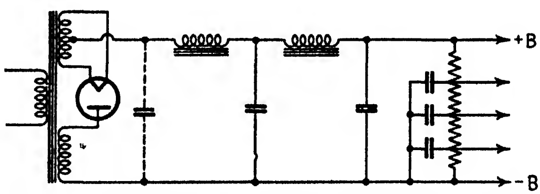


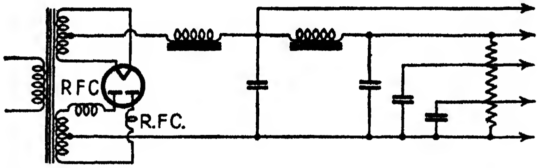
FIG. 120.—A circuit diagram of a half-wave rectifier power supply.

allow the use of smaller chokes and power transformer. The proper intermediate voltages are obtained by the use of series resistors in each lead, as shown in Fig. 119. Figure 120 is the diagram of a half-wave rectifier power supply.

Figure 121 is the diagram of a full-wave rectifier power pack. The radio-frequency chokes (r.f.c.) shown are necessary when mercury-vapor rectifiers are used, for when mercury vapor is used in a rectifier tube, no appreciable current flows until a particular voltage is reached, and then the flow increases at a very

rapid rate. This sudden impact of current causes r-f surges, which, if not suppressed, will make a receiver noisy. The chokes slow up the increase in the current and prevent the creation of hum voltage in other wiring close by.

Figure 119 shows the field coil of a dynamic speaker used as one of the chokes in the power supply. This procedure accomplishes two purposes: It uses the current taken by the set to



G. 121.—A circuit diagram of a power supply using a mercury-vapor rectifi

ıergize the field and, at the same time, saves the expense ıe choke. In some sets, the *IR* drop across the speaker fie ' part of it is used as a source of *C* bias for the power tub his is shown in Fig. 94. A few of the larger permanent publ ldress installations are using a power supply fed from a thre ıase line. There are several good reasons for this.

First, since a large amount of power is required, the three-pha ıe will be badly unbalanced if it is all taken from one pha

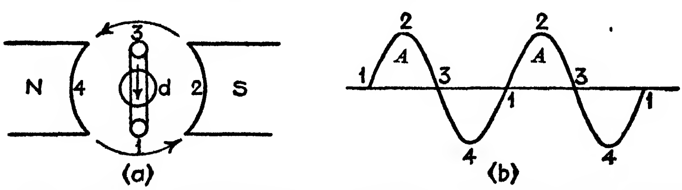


FIG. 122.—Diagram illustrating the generation of single-phase alternating current.

This means that the voltage on the three phases will not be equal, which results in lack of uniformity in the brilliance of lights on the various circuits and other difficulties outside of the scope of this book. Second, the output of a three-phase rectifier is much easier to filter. The output of this type of rectifier may be seen in Figs. 128 and 129 and shows that the variation in the voltage is much less than with single-phase rectifiers and that the variations occur at a much higher frequency. This allows the use of smaller chokes and condensers, which reduce the cost of the filter

materially. This reduction in the cost of the filter is offset to some extent by the fact that from three to six rectifying tubes are required, but these tubes do not have to be so large as those used in a single-phase outfit having the same output.

Three-phase Current.—The easiest way to explain three-phase current is to start with a simple generator to show how three-phase current is generated and what it is.

Let us start with the equipment seen at (*a*) in Fig. 122, which shows a pair of magnetic poles and the end view of a rectangular coil of wire arranged to rotate on the shaft *d*. Voltage is generated in this coil by causing the sides of the coil that run from front to back to cut the magnetic lines of force passing from the north to south pole. When the arrow points to the position 1

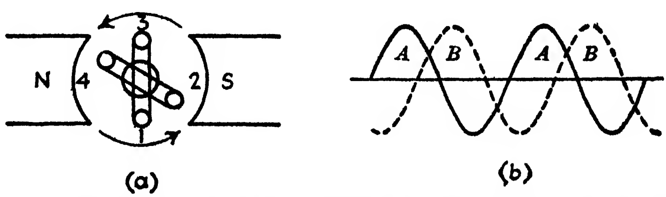


FIG. 123.—Diagram illustrating the generation of two of the three phases of three-phase alternating current.

in diagram (*a*), the coil sides are moving parallel to the lines of force and so are not cutting across any of them. There will, therefore, be no voltage generated. This is indicated at 1 in diagram (*b*). As the shaft revolves, the number of lines of force being cut increases until the arrow points to the position 2 in diagram (*a*). The voltage generated by this movement is indicated by the line from 1 to 2 in diagram (*b*). As the shaft continues to rotate, the number of lines of force being cut decreases until it is again zero when the arrow points to the position 3. The voltage generated as the shaft turned is indicated by the line between the points 2 and 3 on diagram (*b*). During all this time, the side of the coil next to the point of the arrow has been cutting lines of force from the south pole of the magnet. As the head of the arrow passes the position 3, this side of the coil begins to cut the lines of force from the north pole. This reversal of polarity will reverse the direction of the generated voltage. The voltage will build up as the arrow moves from point 3 to point 4, just as it did when the arrow moved from 1 to 2, and

will decrease when the arrow moves from 4 to 1, as it did when the arrow moved from 2 to 3. The voltage generated during this time is indicated by the lines from 3 to 4 and from 4 to 1 in diagram (*b*). The coil has made one complete rotation, and one cycle of voltage has been generated. One cycle of voltage is always generated when the side of a coil passes a north and a south pole.

Now add another coil insulated from the first in the position shown in (*a*) in Fig. 123. This coil is fastened to the same shaft, rotates in the same manner, and generates exactly the same kind of voltage as the first coil. However, the voltages will be out of phase. The phrase "out of phase" means that at any given instant the two coils will be generating voltages at different parts

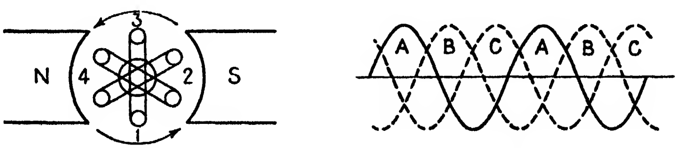


FIG. 124.—Diagram illustrating the generation of three-phase alternating current.

of a cycle. The phrase "in phase" means that at any instant the voltages in the two coils are at the same point in the cycle. For example, if the voltages are in phase, they will be zero at the same time and reach a positive or negative maximum at the same instant. Out-of-phase voltages pass through zero or reach maximum at different times. When the first coil is at the first position, the second one has already gone by that position. The current generated in these coils is shown at (*b*) in Fig. 123.

Add a third coil as shown in diagram (*a*) in Fig. 124. The output of the three coils is shown at (*b*), Fig. 124. This is a three-phase generator with three separate, distinct single-phase currents. The coils are equally spaced in the generator, which causes the voltage peaks to be evenly spaced in time. It will be seen then that a three-phase generator consists of three single-phase generators which are mechanically connected but not necessarily connected electrically. The simple generator shown is a two-pole machine. The large machines usually have a greater number of poles, and it will be found that the coils are arranged so that one side of a coil is under the center of a north

pole when the other side is under the center of the next south pole. This is also true of the two-pole machines. In some machines, owing to the spacing of the slots, it is not possible to have the coils exactly centered under the poles. All the coils that are centered under the poles at one time are connected and form one phase. These coils may be connected in series, in which case the output voltage will be the sum of the voltages in the various coils, but the current rating will be that of a single coil; or the coils may be connected in parallel, in which case the voltage will be that of a single coil, but the current rating will be the sum of the ratings of the individual coils. In a three-phase bank of transformers,

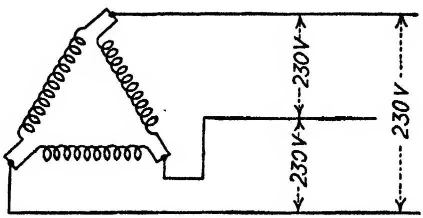


FIG. 125.—Three-phase delta connection showing the voltages from wire to wire.

there are three primaries—one for each phase—and three secondaries—one for each phase. The circuits for connecting three-phase transformers and three-phase alternators are exactly alike.

There are two main ways in which the sets of coils are interconnected in either alternators or transformers. The first connection discussed is known as the "delta" connection. It is so called because it resembles a triangle Δ (the Greek letter delta). There are three coils, or six leads. The combined voltage of two of the coils is equal to the voltage of the third and in the opposite direction. The voltages will buck each other, and no current will flow in the triangle. This is called the "three-phase three-wire system" and is shown in Fig. 125.

The Greek letter ϕ (phi) is also used to express phase, as in the expression "3ϕ three wire." If the same windings are used but with one end of each coil tied together, we have what is known as "three-phase star connection." This is also known as a "Y connection" (see Fig. 126). In this case, the three end wires are brought out and also the common connection, which is called the "neutral." Either connection can be used to connect the three coils in a three-phase alternator used in generating alter-

nating current. Either method can be used to hook the primary or secondary of three different transformers or to hook up the three coils in a motor. The amount of voltage from the transformer will vary from the different hookups. It is possible to hook up the primaries and secondaries differently or both the same way.

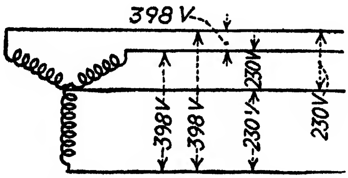


FIG. 126.—Three-phase star or Y connection showing the voltages from wire to wire.

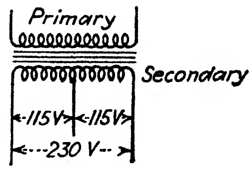


FIG. 127.—Single-phase three-wire connection showing the voltages from wire to wire.

In the single-phase three-wire system, the middle terminal is always grounded and it is also known as the "neutral." This connection is shown in Fig. 127. On a three-phase three-wire system, the same voltage will be received from any wire to another wire. If there were 230 volts across each coil, there would be that voltage across each pair of wires.

Instead of having only one surge of current lasting one half cycle as in single phase, there are three separate surges of current

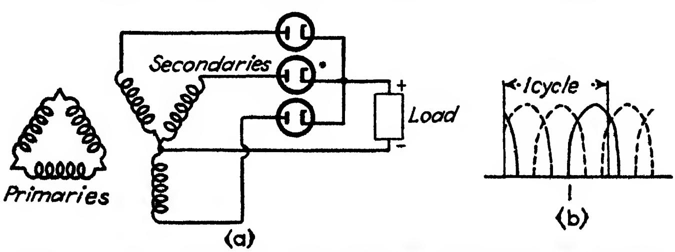


FIG. 128.—Circuit diagram of a three-phase half-wave power supply.

overlapping somewhat, but providing some current for five-sixths of the cycle. Having current provided for a greater portion of the cycle makes filtering in power supplies easier.

Three-phase Power Supplies.—There are numerous methods of connecting up three-phase power supplies, but only three of these are used to any great extent. The first one we shall discuss

will be a three-phase half-wave power supply. The primaries in the three transformers are connected delta and the secondaries, star. It will be noticed that, if a single phase is examined, the circuit is exactly the same as that for single-phase half-wave power supply. The diagram is shown at (*a*), Fig. 128. The output is shown at (*b*) in Fig. 128. It will be noticed that the current varies much less during one cycle than it does for single-phase power supply; therefore, the filtering is very much easier.

The second power supply is three-phase, full-wave. It uses two high-voltage secondaries on each transformer. These

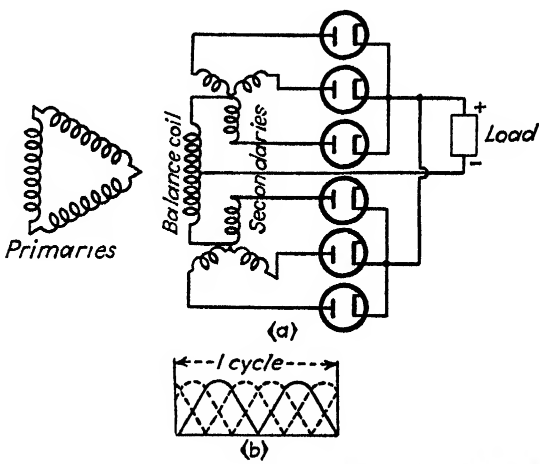


FIG. 129.—Circuit diagram of a three-phase full-wave power supply.

are connected in what is known as a "double-Y circuit." The diagram is shown at (*a*) in Fig. 129. The negative terminal is located at the center of a choke coil. Since all the filament circuits are connected together, it is possible to supply them all from a single-filament transformer winding. The output of this rectifier is shown at (*b*) in Fig. 129. It will be noticed that the output current of this circuit has even less variation than the one preceding it.

The third circuit is three-phase full-wave. The diagram of the connections is shown in Fig. 130. This circuit requires only one high-voltage winding on each transformer, but, since the filaments of the three lower tubes are connected to points having high voltage between them, it is necessary to use a separate

filament winding for each of these tubes. The three upper tubes can all be supplied from a single winding. The output of this circuit is exactly the same as that of the preceding circuit, which is shown in Fig. 129, but this result is achieved with less expensive equipment. In this full-wave circuit, only one high-voltage winding is necessary on each transformer, but four filament windings are required as against two high-voltage secondaries on each transformer and a single filament winding in the double-winding circuit. The three extra filament windings, since they are lower voltage, are much less expensive than the

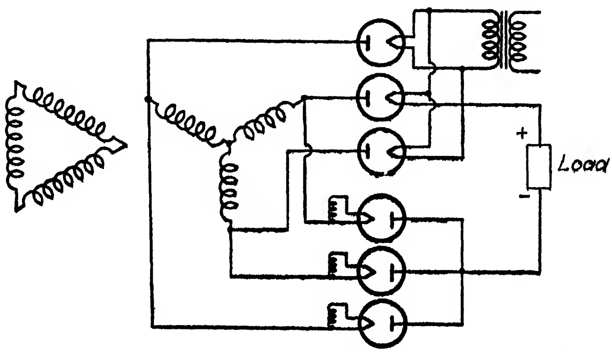


FIG. 130.—Circuit diagram of a three-phase full-wave power supply.

three extra high-voltage windings; therefore, the last circuit is more frequently used.

Design of Power Supply for Use on 115-volt Single-phase Circuits.—The calculations for a power supply must be started at the output end, because definite output voltage and current values are desired. All parts must be built to furnish these values. A power supply furnishing 60 ma. at 250 volts and 20 ma. at 180 volts will be worked out to illustrate the various steps in the design.

Voltage Divider.—About 10 or 15 ma. of bleeder current is usually allowed. This bleeder current serves one very useful purpose in preventing damage due to excessive voltage being applied to condensers and tubes. This protective action is brought about by the *IR* drop in the filter and rectifier caused by the current passing through the resistor. In some of the smaller and less expensive sets, the chokes may have 1,000 or more ohms resistance, which means that the no-load voltage is much

higher than the full-load voltage. If no bleeder resistor is used, the plate and screen-grid by-pass condensers are subjected to the no-load voltage from the time the sets are turned on until the tubes have warmed up sufficiently to draw plate current; therefore, sets using series resistors for voltage regulation must use condensers with higher voltage ratings than would be necessary if a bleeder resistor were used.

There are two ways of determining the values of the two sections of the voltage divider. The first is by experiment. The first step is to determine the bleeder current desired. A satisfactory value is 15 ma. With the maximum voltage of 250 volts, the value of the resistance required to limit the current to 15 ma. can be found by using Ohm's law, $R = \frac{E}{I} = \frac{250}{0.015} = 16{,}666$ ohms. A 16,500-ohm resistor would be satisfactory. The bleeder current will no longer be 15 ma. when the 20 ma. is taken from the 180-volt tap, but the change will have little effect on the operation of the set. The location of the 180-volt tap can be found by trial if an adjustable resistor is used. Since 180 volts is more than half of the 250 volts and since the current in the portion of the resistor between the 180-volt tap and the 250-volt end of the resistor is heavier than in the other portion, it is easy to see that the tap will be located near the 250-volt end of the resistor. A safe method of arriving at the proper setting of the tap is to place the slider temporarily at a point just above the center of the resistor and then read the voltage with the set drawing current. Since the voltage is purposely set low, no damage can occur due to high voltage or excessive current. The slider can then be gradually moved toward the 250-volt end of the resistor until the proper voltage is secured. The wattage of the resistor can be found from the formula $W = I^2R$. The I substituted in the formula must be the maximum current in any portion of the resistor. In this case, it will be in the portion between the 250-volt end and the 180-volt tap. The current in this portion will be 20 ma. for the 180-volt tap plus the 15-ma. bleeder current, or a total of 35 ma.

$$W = (0.035)^2R = 0.0012 \times 16{,}500 = 19.8 \text{ watts.}$$

A 25-watt resistor would be used.

The second method uses computation to determine the resistance on each side of the tap. The value of the resistor between the 250-volt end and the 180-volt tap can be found by using Ohm's law. The voltage across this resistor is 250 − 180, or 70 volts; the current through it is 20 + 15, or 35 ma.; and $R = \frac{E}{I} = \frac{70}{0.035}$, or 2,000 ohms. The wattage rating of this resistor is $W = EI$, or $70 \times 0.035 = 2.45$ watts. A 3- or a 5-watt resistor could be used. The wattage rating can also be determined from the formula $W = I^2R = (0.035)^2 \times 2{,}000$, or

$$0.001225 \times 2{,}000 = 2.45 \text{ watts.}$$

The value of the other resistor is found in the same manner. The voltage across it is 180 volts; the current through it is the bleeder current only, 15 ma. $R = \frac{E}{I} = \frac{180}{0.015} = 12{,}000$ ohms. The wattage rating is $W = EI$, or

$$180 \times 0.015 = 2.7 \text{ watts.}$$

A 5-watt resistor would be suitable.

Filters.—The filter consists of one to three chokes in series with the line and two or three condensers connected across the line. The chokes are usually in the positive side of the circuit although a single choke, often the speaker field, is sometimes connected in the negative lead so that the drop across it may be used as a *C* bias on some of the tubes.

When high voltage and low current are needed, the desired amount of filtering can be obtained most economically by the use of large chokes (about 25 or 30 henrys) and relatively small condensers (2 to 25 mf. depending on voltage). The voltage loss in the chokes will be only a small percentage of the total and will not be excessive because of the low current. When low voltage and high current are required as for A battery eliminators, the use of high values for the chokes is impossible, because the *IR* drop in them would be excessive at the higher values of current required. For this reason, smaller chokes (approximately ½ henry) and very high capacity condensers are used. These condensers are often 2,000 and 4,000 mf., but since they are used on low-voltage circuits an electrolytic condenser of this size can

be made with reasonable dimensions and cost. The degree of filtering will be practically the same with either type of filter.

It is possible to estimate the value of the voltage required for the power winding, but it requires a considerable amount of computation and involves the estimation of the charging current of the condensers. A much simpler way to get the required value accurately is to build the filter, voltage divider, and rectifier complete. The filament of the rectifier should be supplied with the proper voltage from a separate transformer or from a storage battery. The power supply for the high voltage should be obtained from a separate transformer that has a rheostat in the primary or other means of regulating the primary voltage. The primary voltage is then adjusted until the required d-c

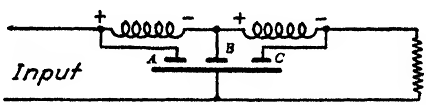


Fig. 131.—Circuit diagram of a power-supply filter illustrating one of the possible causes of failure.

voltage is obtained at the voltage divider. The secondary voltage then is the required voltage. The proper transformer can then be purchased or constructed.

The design of filter chokes carrying pulsating current is too complicated for a book of this type. Any college textbook on radio engineering will give the details.

Filter Condensers.—Separate cans for electrolytic condensers are much better than a single can containing several condensers. When condensers having several positive terminals are used, they are connected to various points in the filter that have different voltages, due to the *IR* drop in the chokes. Excessive leakage is frequently found in these condensers because some of the positive plates are actually negative in respect to the other positive plates. This condition is illustrated in Fig. 131. Owing to the *IR* drop caused by the resistance of the chokes, the polarity will be as indicated on the figure. It will be seen that the positive plate *B* is negative in respect to the positive plate *A* and that the positive plate *C* is negative in respect to both *A* and *B*.

Paper filter condensers are much better for public-address amplifiers that are not in frequent use, because the electrolytic

condensers deteriorate when not frequently charged and when used after a period of idleness will draw heavy leakage current that may be large enough to damage the power transformer, rectifier, or one of the chokes.

On some sets, a tapped choke, as shown in Fig. 132, is used. The circuit *LC* is tuned to the frequency that is causing the most difficulty. The fundamental frequency, 60 cycles for a half-wave rectifier and 120 cycles for a full-wave rectifier, will give the highest readings on a meter; however, since amplifiers frequently slight these frequencies and since the human ear is less sensitive to them, it is often advisable to tune this circuit to one of the higher harmonics that is more noticeable to the ear.

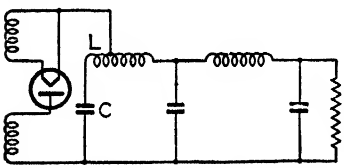


Fig. 132.—Circuit diagram of a power-supply filter using a tuned choke.

Power Transformers.—Commercial power transformers are dried out by baking in an oven after being constructed. They are placed in a tank from which all the air is pumped and then, while still in the same tank, they are submerged in a vat of insulating compound, and air pressure is placed on top of that. Since the air is removed from all the cracks and crevices, the compound is forced into every cranny. This increases the heat-dissipating ability of the transformer and protects it from moisture and corrosion. Since these processing steps are impossible for the serviceman to carry out, it is impossible for him to wind a transformer that can be guaranteed to stand up. It, therefore, is not profitable to wind transformers except either for replacement purposes when the proper transformer cannot be purchased and the customer cannot be persuaded to buy a new set or for test equipment to be used by the serviceman himself. As an aid in winding transformers for these special purposes, the following steps in the design of a transformer are given:

1. *Choosing the Core.*—The size of the core depends on the power output of the transformer. The output is found by using the power formula $W = EI \cos \theta$, in which E is the secondary voltage, I is the secondary current, and $\cos \theta$ is the power factor. The power factor of radio transformers can be assumed to be 0.90. The power, then, is found by multiplying the secondary volts by the amperes and the result by 0.90. If there is more than one

secondary, the total output is found by adding the outputs of the separate windings. The power in the primary must be greater than that in the secondary, for the transformers are never 100 per cent efficient. Radio transformers can be assumed to be 60 to 70 per cent efficient; so the power in the primary

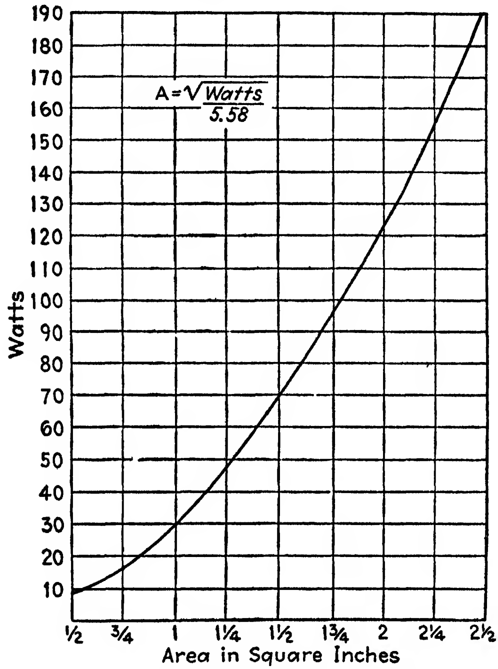


FIG. 133.—To find the required core area for a transformer locate the value of the watts output at the left edge of the chart. Follow the horizontal line to the right until it crosses the curve and then follow the vertical line down to the bottom line. The required core area is given here.

can be found by dividing the secondary power by 0.6 or 0.7. These mathematical operations are shown in the following formulas:

$$W_s = 0.9E_1I_1 + 0.9E_2I_2 + 0.9E_3I_3 + \cdots$$

$$W_p = \frac{W_s}{0.70},$$

in which E_1, E_2, E_3 represent the voltages of the various secondaries; I_1, I_2, I_3 represent the current in amperes in the various secondaries; W_p represents the primary watts; W_s represents the secondary watts.

After the power in the primary has been found, the size of the core can be found from the formula $A = \frac{\sqrt{W_p}}{5.58}$, A being the area in square inches of the portion of the core around which the wire is to be wound. The graph given in Fig. 133 is constructed from

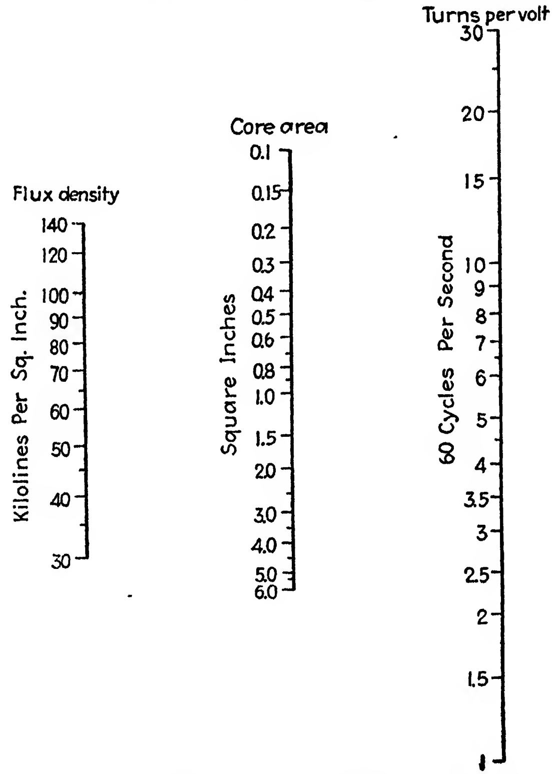


FIG. 134.—To find the turns per volt for a transformer place a ruler or straightedge so that it passes through the values which have been found for flux density and core area. The intersection of the straightedge and the turns-per-volt line will then give the required information.

this formula. The size of the opening for the wire cannot be determined until the number of turns and the size of the wire are known. This opening should be as small as possible; otherwise the magnetic circuit is unnecessarily long, which results in high leakage reactance and a poor transformer.

2. *Turns per Volt.*—The number of turns of wire per volt is the same for all the windings. It is found from the formula

$\frac{N}{E} = \frac{100,000,000}{BAf4.44}$, in which $\frac{N}{E}$ represents the turns per volt. A is the core area in square inches, f is the frequency, and B is the magnetic density. Lower values of B are safer than higher ones, an average value being 65,000. The chart shown in Fig. 134 has been developed from this formula.

3. *Number of Turns for Each Winding.*—The number of turns in each of the windings is found by multiplying the turns per volt $\frac{N}{E}$ by the voltage desired in the winding. If the windings are to be tapped, it is wise to make slight changes in the turns per volt so that the taps will not come at a fraction of a turn.

4. *Size of the Wire.*—The size of the wire to be used can be found from tables of the carrying capacity of magnet wires. One thousand circular mils per ampere should be used for transformers under 50 watts and 1,500 cir. mils per ampere for larger transformers. The current in the primary can be found from the formula $I_p = \frac{W_p}{E_p \times 0.9}$. For the secondaries of filament transformers carrying heavy current, two or three wires can be wound at the same time and connected in parallel. The sum of the capacity of the parallel wires should be the required carrying capacity. Some windings delivering high values of current are wound with copper ribbon. When winding the larger sizes of wire, use extra care to prevent the force necessary to wrap the wire around the form from damaging the insulation of the layers beneath.

5. *Winding Space.*—Now that the size of the wire for the various coils and the number of turns of each are known, the space required for the winding can be found by using a table giving the turns per square inch of the various sizes of wire. Liberal allowance must be made for insulation between layers; and, if the wire is guided by hand, when the coil is wound, allowance must be made for the inevitable space left between turns.

Hints on Winding Transformers.—1. A wood winding mandrel should be constructed with a cross section $\frac{1}{32}$ in. larger each way than the core and about 6 in. long.

2. A bobbin for the wire, made of $\frac{1}{32}$-in. fiber, is a very good way to insulate it from the core. This bobbin can be constructed by wrapping a strip of fiber around the mandrel to form the

tubular part and fitting the ends so that they fit tightly over the extreme ends of the fiber strip. The liberal use of Duco cement at the joints will hold the ends in place securely. The red fiber will not crack at the corners when being bent around the mandrel if it is first thoroughly soaked in water. Care should be used to see that the bobbin is not cemented fast to the mandrel before the winding is started, or it may be wrecked in trying to remove the mandrel. When the large sizes are being wound, it is well to reinforce the bobbin by driving finishing nails close to the ends in the mandrel, or by nailing blocks next to the ends.

3. Be careful to bring the ends of the windings out at the sides of the bobbin that will not be covered by the core when it is put in place.

4. Waxed paper, obtained from burned-out paper condensers, is very convenient to use between layers.

5. Be very careful to prevent the end turns of one layer from coming in contact with the turns of adjacent layers, for there will be considerable voltage between them, and a breakdown of the insulation may occur.

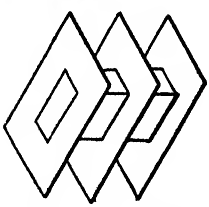


FIG. 135.—When a center-tapped winding is desired, a bobbin having a central partition should be used to separate the two halves of the winding.

6. Where center-tapped windings are to be used, the bobbin should have a partition in the center with half the winding placed on each side, as shown in Fig. 135. If this is not done and one half is wound over the other, the outer winding will have higher resistance and inductance. This will cause the voltage on this half to drop more under load than the inner half. This unbalanced voltage gives rise to a hum, to eliminate which requires additional filtering.

7. The voltages used in all the foregoing calculations are open-circuit voltages. They will all drop under load. To predetermine this drop is impossible without accurate data on the magnetic qualities of the core used, and these are seldom available. The drop can be kept low by using a low value of turns per volt, which demands a large core and the use of generous-sized wire in the coils.

8. Use care in putting the last few laminations in place, as they may cut through the bobbin and ground the primary if much force is used.

9. The core should be assembled so that the joints in adjacent layers do not come in the same place.

Series or Parallel Connection of Transformer Windings.—Before two windings are interconnected, the direction of the voltage in each at a certain instant must be considered. Since the current does not reverse during one half cycle, it can be considered as direct current for that period of time. Any connection that would not cause a short circuit in a d-c circuit having the voltages of the same polarity as those in the a-c circuit during a half cycle will not cause a short circuit in an a-c circuit. It is therefore proper to speak of the polarity of an a-c circuit. It refers to the polarity—whether a particular terminal is positive or negative—in reference to other terminals at some particular instant or for a particular half cycle. A terminal of a transformer is considered positive if the current is flowing out of the transformer from this terminal at the instant under discussion. If at the same instant the current is flowing into the transformer at some terminal, then that terminal would be considered negative. Once the polarity of the terminals of the windings is known, the connections can be made as for a d-c circuit. Connecting positive to negative will add the voltages, and connecting positive to positive and negative to negative will give a parallel connection.

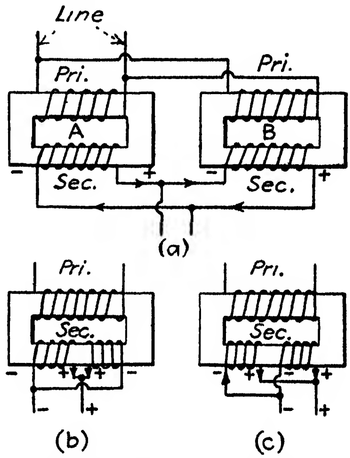


FIG. 136.—Part (*a*) shows the wrong connections for parallel operation of two windings. The correct connections are illustrated in parts (*b*) and (*c*).

The arrows in Fig. 136 show the direction of the voltage in the coils during one half cycle. In an actual transformer, the direction of the voltage at the terminals would depend on the direction in which the coils were wound and also on how the leads were brought out to the terminals. By tracing the secondary circuit in Fig. 136 and noting the direction of the arrows, it is evident that the circuit (*a*) is a dead short circuit, for the voltages in both windings are causing current to flow in the same direction. This

circuit is similar to connecting two dry cells together + to − and then connecting the other two terminals with a piece of wire. In diagrams (*b*) and (*c*), the voltages of the two coils are bucking each other in the loop, and, if they are equal, no current will flow in this circuit. These circuits are similar to connecting two dry cells + to + and − to −. The method of determining the correct connection is very simple.

1. With the secondaries open, connect the two primaries in parallel permanently. One primary terminal of each transformer should be connected to one side of the line and the other two terminals to the other side. It is essential that the primaries be connected permanently because reversing one of them will also reverse its secondary and cause a short. Reversing both primaries reverses both secondaries and leaves them in the same relation to each other.

2. Connect one terminal from each secondary together.

3. Connect a voltmeter across the other terminals. The reading of the meter will be either the sum or the difference of the voltages of the two windings. If it is the difference, which will be zero if the windings have the same voltage, it indicates that two terminals having the same polarity are connected. If the voltmeter reading is the sum of the voltages of the windings, then terminals having opposite polarity are connected. The latter connection would be for series operation of the windings. When the series connection is used, the total current that can be used is limited by the capacity of the smaller winding, for the same current flows through both.

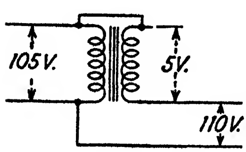


Fig. 137.—Booster transformer connections.

Booster Transformer Connection.—In some localities it is found that poor reception is caused by low line voltage. If this condition exists during all of the time that the radio is in operation, it can be corrected by using a booster transformer. In most cases a 2.5- or a 5-volt filament transformer can be used. It is connected as shown in Fig. 137. The proper end of the secondary to connect to the primary can be determined by trial. If the wrong end is connected, the line voltage will be reduced. This connection is useful when difficulty is encountered with tubes burning out rapidly due to excessive line voltage. The

secondary winding should, of course, be capable of carrying the full line current of the set. The wattage rating of the booster transformer can be found roughly by multiplying the secondary voltage by the line current required by the set. This result should be increased about 20 per cent to ensure cool operation of the transformer.

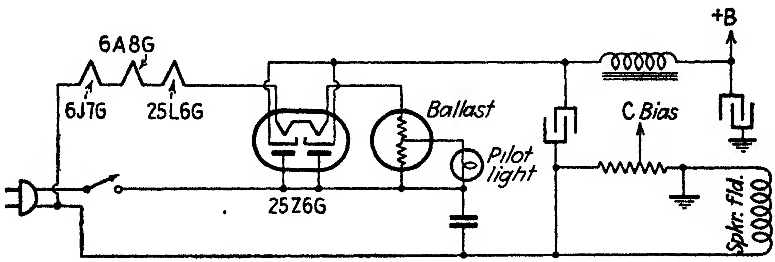


FIG. 138.—An a-c d-c power supply.

Two identical windings in parallel can furnish twice the current that one can. If the windings have different ratings, it is not wise to put them in parallel because each will try to deliver half the load, which may overload the smaller winding. In this case, it is better to connect the transformers to separate loads according to their capacities. It is not good practice to connect two transformers of different make or model or two windings on the

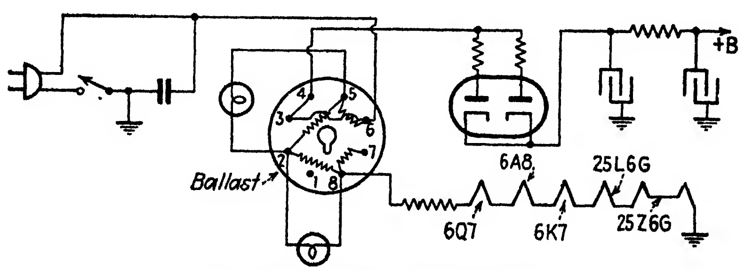


FIG. 139.—An a-c d-c power supply.

same transformer in parallel even though the voltages on no load are the same, because the voltages may not drop the same amount under load, which will result in current circulating between the transformers and an unequal division of the load. Excessive heating of the transformers would indicate this condition.

Transformerless Power Supplies.—The transformerless power supply was designed to meet the demand for a compact, inexpensive power supply for small sets. Eliminating the transformer lessened the cost and size of the chassis and also removed the source of much of the hum, particularly in a compact set.

A-C D-C Power Supplies.—The circuits of three a-c d-c power supplies are shown in Figs. 138 to 140.

When these power supplies are used on direct current, the plug should be inserted so that the positive side of the line is connected to the plates of the rectifier. The plate voltage then will be the line voltage less the loss in the tube and the filter choke or resistor.

When alternating current is used, the rectifiers operate in a half-wave circuit. The input condenser of the filter would be

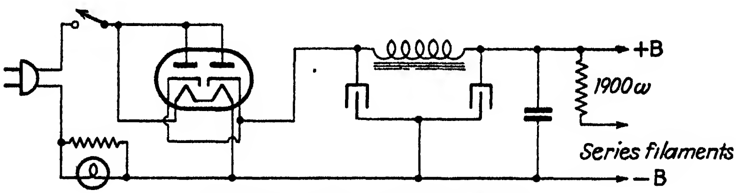


FIG. 140.—An a-c d-c power supply.

charged to the peak line voltage if the set did not draw any current. This voltage then would be 1.73 times the r.m.s. line voltage. This accounts for the fact that these sets have more power on alternating current than on direct current. The drain of the set lowers this voltage by an amount depending on the current requirements. The rectifier passes current only during that portion of the cycle when the instantaneous positive voltage is in excess of the voltage across the input condenser. Furthermore, all of the current required must flow through the rectifier during this small portion of the cycle. For this reason, the maximum peak current rating of the rectifier is often more important than its continuous current rating.

Increasing the size of the input condenser increases the output voltage and therefore decreases the portion of the cycle during which current flows. The higher voltage also requires more charging current. The increase in the peak current often overloads or ruins the rectifier. The difficulty is particularly severe

when the set happens to be turned on at the peak of a positive half cycle. The cathode has not had time to warm up and the tube must pass the full charging current of the input condenser and start to supply the load to the set as well. Unless this demand is well within the rating of the tube it probably will fail. Incidentally, if it shorts when it fails, alternating current will be put across the filter condensers and they will also be ruined. The excessive peak current can be controlled by placing resistors

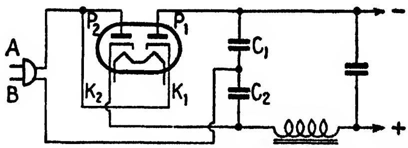
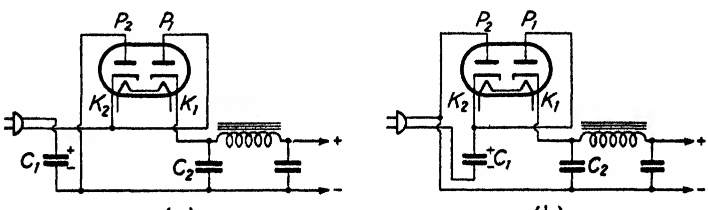


FIG. 141.—A full-wave voltage doubling power supply.

in series with the rectifier plates as shown in Fig. 139. These resistors are often from 25 to 50 ohms.

Voltage Doubler Power Supplies.—The circuits shown in Figs. 141 and 142 illustrate two methods of obtaining voltages in excess of the line voltage for the plate circuits of a set.

When the line terminal A in Fig. 141 is positive, the condenser C_2 is connected across the line through P_2-K_2 and is charged to nearly peak line voltage. When the terminal B is positive, the



(a) (b)

FIG. 142.—Diagrams of half-wave voltage doubling circuits.

condenser C_1 is connected across the line through P_1-K_1 and is charged to nearly peak line voltage. Since these condensers are in series across the load, the load voltage will be the sum of the voltages across the two condensers. Since the set is continuously drawing the charge from the condensers, the actual voltage obtained will be less than twice the peak voltage.

The current fed to the filter by this circuit will be like that from a full-wave rectifier. If the two condensers C_1 and C_2 have

unequal capacity, the output will have a 60-cycle hum in it which the usual filter will not be capable of handling.

The circuits shown in Fig 142 illustrate two half-wave voltage doubler circuits. In both of these circuits the condenser C_1 is charged to nearly peak line voltage through P_2-K_2 when the top prong of the plug is positive. When the bottom contact of the plug is positive, the line voltage adds to the voltage across C_1 and both feed the load through P_1-K_1. The output is therefore half-wave.

FIG. 143.—A synchronous vibrator. Note the four contacts

The maximum peak current presents the same problem in these circuits as in the foregoing ones and can be limited by resistors in the same manner.

Direct-current Power Supplies.—Direct-current power supplies are divided into two groups, depending on the source of power. The first group derives its power from storage batteries; the second, from the 115-volt d-c commercial circuits. The first group is subdivided into two types: those using a vibrator and those which are essentially motor generators.

Vibrator-type Power Supply.—There are two varieties of this type of power supply: One, known as the synchronous vibrator type, is shown schematically in Fig. 144. The other, nonsynchronous type is illustrated in Fig. 146. Power supplies using either of these circuits are used on 6- or 32-volt batteries. Higher voltages than these are seldom used with vibrators since the difficulty with the contacts increases as higher voltage is used.

The operation of a synchronous vibrator can be understood by referring to Fig. 144. When the switch is closed, sufficient current to operate the vibrator reed flows through the lower half of the transformer primary *P* and through the vibrator coil *V* to ground. The movement of the vibrator reed *R* closes the lower contacts *A* and *B*. The lower contact *B* has two functions: It puts a short circuit across the coil *V*, which allows the reed *R* to spring back and close the upper contacts *A* and *B*. When the lower contact *B* is closed it also allows the full battery voltage to be impressed on the lower half of the primary *P*. The sudden surge of current in the primary of the transformer induces a voltage in the secondary. Since the current in the primary is flowing

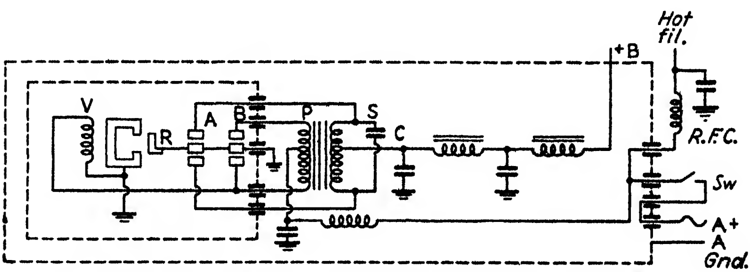


FIG. 144.—Circuit diagram of a synchronous-vibrator power supply.

down, the voltage in the secondary will be directed upward. However, only the lower contact *A* is closed, and so the current flows from ground through the lower contact *A*, the lower half of the secondary, and out to $+B$ and returns to ground. The same voltage is generated in the upper half of the secondary but, since the upper contact *A* is open, no current flows in this portion of the transformer. When the upper contacts *A* and *B* are closed, the primary current flows upward and the secondary voltage is directed downward. The secondary current flows now from ground through the upper contact *A*, the upper portion of the secondary, out to $+B$, and returns to ground. At the same time, the lower contact *A* is open, and no current flows in the lower half of the secondary.

As soon as the lower contact *B* is opened, the short is removed from the coil *V*, which causes the reed to close the lower contacts again, and the operation repeats. As can be seen from the diagram, the high-voltage filter is of the conventional type. An

r-f choke is often placed in series with the a-f chokes to choke out the radio frequency produced by the vibrator. Small condensers are frequently put in parallel with the larger filter condensers, because the larger condensers usually have sufficient inductance to prevent them from by-passing the radio frequency coming from the vibrator. The smaller condensers, especially those having flat plates—the mica-bakelite variety—have much less inductance than those with rolled-up plates such as the tubular or the electrolytic varieties.

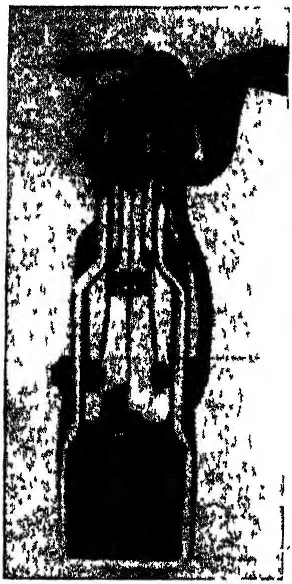


FIG. 145.—A nonsynchronous vibrator.

Plus or Minus A Grounded—If the circuit shown in Fig. 144 is used in a car that has the positive *A* grounded, considerable damage may be done. In tracing the path of the current under these conditions in the circuit shown in Fig. 144, it will be found that when the lower contact *B* is closed the current will flow up in the primary and the voltage generated in the secondary will be downward. Since the lower contact *A* is closed, the secondary voltage will be positive at ground. This reverses the polarity of all the electrolytic condensers in the power supply and also all the plate by-pass condensers in the set. All voltages can be made normal by reversing the two leads from the transformer

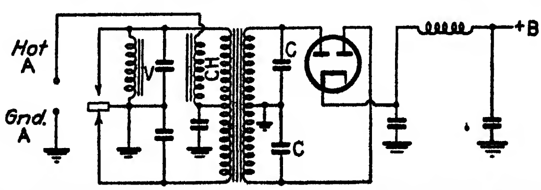


FIG. 146.—Circuit diagram of a nonsynchronous-vibrator power supply.

either to the contacts *A* or to the contacts *B*. In the original circuit, the lower half of the transformer primary is used at the same time that the lower half of the secondary is operating. To reverse the polarity, the upper half of the secondary operates

at the same time that the lower half of the primary is used. Those changes are usually easily made at the socket into which the vibrator is plugged. This type of vibrator is being discontinued, mainly owing to difficulty with the contacts and because the "hash," the electrical disturbance, caused by it is very severe.

The operation of a nonsynchronous vibrator can be followed by referring to Fig. 146. Contacts are used in the primary circuit only. The operation of these contacts is exactly like the primary contacts of the synchronous vibrator. Alternating current at a high voltage is induced in the secondary and is rectified by exactly the same circuit as an a-c power supply. The

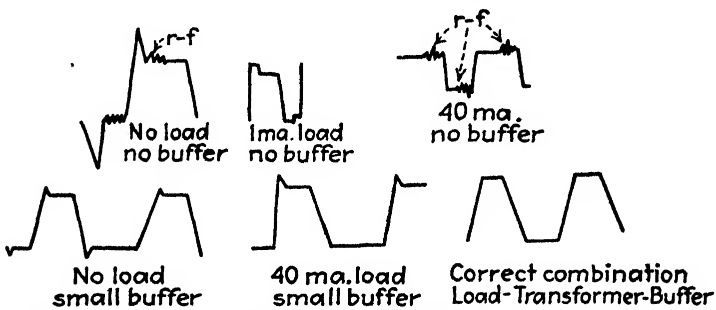


FIG. 147.—Oscillograph tracings of the output wave shape of a vibrator power supply showing the effect of the buffer condenser and load.

rectifier used must be of the cathode type, for the heater will be at $-B$ potential while the cathode is at $+B$ potential.

The condensers marked *C* in Figs. 144 and 146 are called "buffer condensers." Their purpose is illustrated in Fig. 147, which gives oscillograms of the output of the transformer under the conditions shown.

If these condensers are not used, the secondary peak voltage will be very high, which will have a tendency to break down the insulation of the filter condensers and other condensers in the plate circuits of the set. The value of these condensers is critical and must be maintained at the value specified by the manufacturer. In fact, the vibrator, transformer and the buffer condensers all work together to produce a satisfactory output; if any other elements are substituted for the originals, the output will be unsatisfactory. Each vibrator has a natural period of vibration and produces an alternating current

of that frequency. It is essential that the transformer be designed to use current of this frequency. The size of the buffer condensers must be just right to match the output of the transformer and is also dependent on the load required by the set. If the size of the buffer is too small, it will not properly reduce the high voltage peaks. If the capacity is too large, it will increase the current drain from the battery and shorten the life of the contacts.

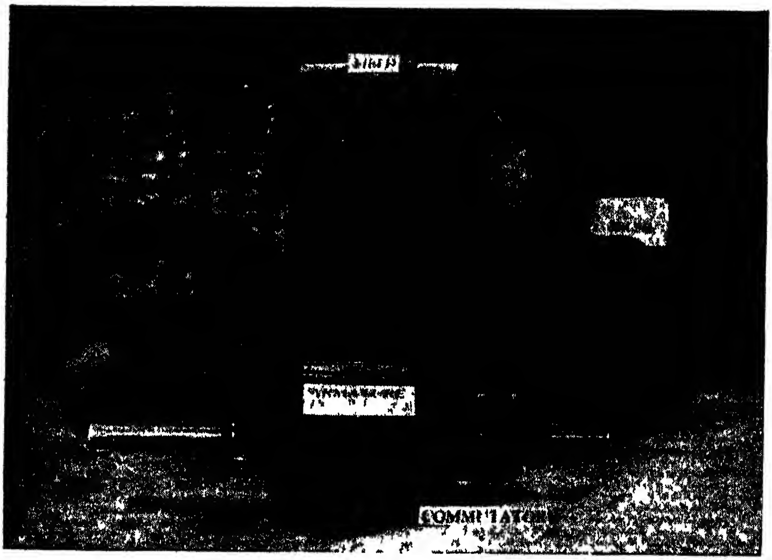


FIG. 148.—Disassembled view of a d-c motor.

The starting voltage is one of the best tests of the worth of a vibrator. A vibrator in good shape will start on a voltage of 5.2 or less. If it requires between 5.2 and 5.6 volts, it is of doubtful worth; if a higher voltage is required, it should be replaced. Another good check is a voltmeter across the output. Low and unsteady voltage indicates that the vibrator should be replaced, provided, of course, that other parts of the power supply are in good condition.

Motor-generator Type of Power Supply.—Since the radio serviceman often finds not only that motors and generators are a source of the noise that he is trying to eliminate but also that motor-generator sets are used for power supply and as converters

to change direct to alternating current, or vice versa, some of their characteristics should be discussed.

There is very little, if any, difference between a d-c generator and a d-c motor. Either machine can be used for the other purpose. The principal part of a generator is the frame, which also provides a magnetic path for the field flux. This flux is created by coils placed on the poles, which are metal projections extending from the frame toward the center. The coils are known as the "field coils." The armature is the rotating part having a number of slots on its surface in which the armature coils are wound. The ends of the armature coils are soldered to segments of the commutator, which is a copper cylinder made of many segments, each insulated from the others by mica. The

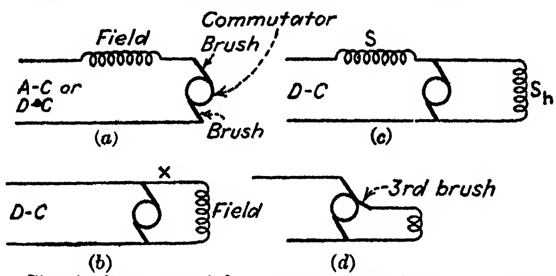


FIG. 149.—Circuit diagrams of d-c motors: (a) series motor, (b) shunt motor, (c) compound motor, (d) automobile generator using the third-brush method of voltage control.

brushes are held in contact with the commutator by springs and are used to conduct the current from the armature coils to the external circuit. There are three main ways of connecting the armature, field, and external circuit. In the series motor, the armature and field are in series as shown at (a) in Fig. 149. The universal-type motor is usually of this sort. Since the field is in series with the armature, it must carry the full motor current. It is, therefore, wound with comparatively few turns of rather heavy wire. The speed of this motor decreases rapidly as the load is increased. With no load the speed may increase to a point where the motor will tear itself apart. For this reason it is always directly connected to a load.

The shunt-motor field is connected as a shunt across the armature as shown at (b) in Fig. 149. It therefore has the full line voltage across it. It is wound with a large number of turns of fairly small wire.

The speed of this type of motor is fairly constant; however, it drops slightly as the load increases. This motor will not exceed a safe speed with no load. This is the type of d-c motor generally used.

Speed Control.—The speed can be increased by introducing a resistance at the point marked x. Reduced speed is obtained by placing resistance in the supply line. When the machine is operated as a generator, increasing the resistance at x lowers the output voltage.

It must be remembered that the power developed by a motor is obtained from the attraction and repulsion of the armature and field magnetic fluxes. If the speed is increased by weakening the field flux, the power output will decrease unless the armature draws enough extra current to increase its flux. If the speed is increased, it usually puts more load on the motor rather than less so that it is necessary to check the heating in the armature when used in this manner. The increased armature current often causes excessive sparking at the brushes also.

Inserting a resistance in the line to decrease the speed simply deprives the motor of an amount of power from the line equal to the I^2R loss in the resistor and, therefore, the power output drops by that amount.

It is interesting to note that any d-c motor, when it is running, is also a d-c generator for there are armature turns of wire cutting the field flux and in Chap. I it was stated that when a conductor cuts lines of force a voltage is generated. This voltage in a motor is known as the back e.m.f. or counter e.m.f. It is in opposition to the line voltage. In fact it "bucks out" or counterbalances enough of the line voltage so that the remaining line voltage, or the effective line voltage, is just enough to force sufficient current through the armature to develop the required power. If the load is increased, the motor slows down. This decreases the number of lines of force cut by the armature conductors per second and this in turn decreases the back e.m.f. The increased effective or remaining line voltage causes more current to flow through the armature, which produces the power to carry the increased load.

The resistance of an armature is very low. Consequently, it is necessary to connect a resistor in series with it for starting. As the motor picks up speed, its back e.m.f. increases and the resist-

ance can be cut out step by step. For fractional horsepower motors this is not necessary because their armatures have higher resistances and, since they are light, they can come up to speed and build up a back e.m.f. before the high current can damage them.

The compound motor, shown at (*c*) in Fig. 149, is used when very constant speed with varying load is required. When used as a generator, this machine can be designed to have constant voltage for any load. As the load increases, the shunt field s_h weakens but the increased current through the series field strengthens it and keeps the total field strength at the proper value to maintain constant voltage.

Automotive generators are connected as shown at (*d*) in Fig. 149. Moving the third brush nearer to the upper main brush increases the voltage across the field and therefore the current through it. This increases the field magnetism, which in turn raises the output voltage. This increased voltage is able to force more charging current through the battery. This type of generator should never be operated without a load, because the voltage will increase to a value that will puncture the insulation.

Trouble Shooting on Motors and Generators. *Bearings.*—Most small rotors and generators have oil wells and wicks that feed oil to the bearings. These wells should be checked about four times a year. Some of the newer machines have self-oiling bearings. These bearings are made of a porous bronze that is saturated with oil and require no attention. Figure 150 illustrates the ring type of oiler. It consists of a brass or bronze sleeve bearing with a portion of the upper part cut away so that a ring can hang on the top of the shaft. The lower portion of this ring then dips into an oil well. As the shaft revolves, the ring rolls around and continuously draws up oil to the top of the shaft. With this type of bearing the oil level should be watched and the ring inspected to see that it is rolling. If the oil becomes low and gets gummy, the ring often sticks in one spot. This wears a groove in the ring where it hangs on the shaft. If this occurs, it will no longer roll and must be replaced or at least have its inner surface trued up.

There are two types of ball bearings: One is totally enclosed and is lubricated for the life of the motor at the factory. This type should require no attention. The other, more open type

should be repacked about once a year for average use. The type of grease used will depend on the size of the bearing and on the temperature at which it operates. All bearings require lubrication; however, in the case of electrical machinery too much oil is as bad as too little. Oil should not be allowed to get on the windings or on the commutator.

Brushes.—The brushes are kept in place by brush holders and are held in firm contact with the commutator by springs. The brushes should slide easily in the holder and should be long enough so that the springs can perform their function.

When new brushes are installed, it is necessary to fit them to the curvature of the commutator. This is done by putting the brush in the holder in the normal manner. A strip of sandpaper is placed on the commutator under the brush with the rough side toward the brush. It is important that the entire strip of sandpaper be kept in close contact with the commutator. The armature is then rocked back and forth until the end of the brush has the proper curvature. Emery cloth or paper should not be used, for the emery is an electrical conductor, and if particles of it lodge between the commutator segments they will create a short circuit.

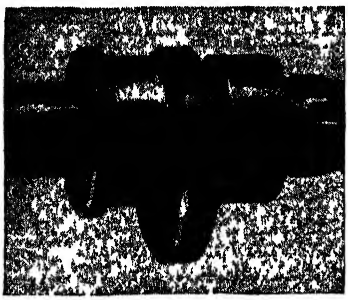


FIG. 150.—A sleeve-type bearing showing a ring oiler.

Commutators.—Commutators should not be lubricated. After considerable service, the copper may wear down, leaving the mica sticking up above it. This causes severe sparking, which rapidly increases the difficulty.

Method of Undercutting the Mica.—To do this the armature should be removed. If the commutator is grooved by the brushes or if the mica is noticeably high, the commutator should be turned in a lathe. Be careful not to disturb the connections of the armature coils. The next operation is to undercut the mica. To prevent damage to the windings and to the bearings, it is best to support the armature while working on it by putting the end of the shaft opposite from the commutator in a hole, slightly larger than itself, drilled in a board about 1 in. thick held in a vise. The tool used is made by grinding both sides

of a piece of hack-saw blade to remove the "set" from the teeth. Hold the blade so that the teeth cut as the blade is pulled toward you. The teeth should be placed over one of the mica segments and then carefully pulled toward the operator. The cut should be about $\frac{1}{32}$ in. below the surface of the copper. Care should be used to see that the full width of the mica is removed. Look out for a thin layer left sticking to the copper at the sides of the cut. Try to avoid scratching up the surface of the commutator, as any roughness will cause sparking at the brushes, which will rapidly increase the trouble.

Fig. 151.—Undercutting the mica on a commutator.

Speed Control.—Increased speed can be obtained from a motor by placing resistance in the field circuit; however, this reduces the available power output. If the speed is increased much above normal, watch the armature for signs of heating and for sparking at the commutator.

Reduced speed can be obtained by placing resistance in the supply line. This also reduces the power output.

Voltage Control for Generators.—Increased voltage can be obtained by increasing the speed. Variable voltage control can be secured by putting a rheostat in the field circuit. Increasing the resistance lowers the voltage.

Dynamotor.—A power supply using a dynamotor to supply high voltage to the Atwater-Kent model 756 automobile radio is shown in Fig. 152. A dynamotor may be said to be a motor and a generator using the same field structure and with the two sets of

armature coils wound on the same armature. Two commutators are used, one at each end. Usually the commutator of the motor has fewer segments than the generator. The larger number of segments on the generator commutator produce a higher frequency ripple at a lower ripple voltage, which makes filtering easier. The shunt field coils *SH* maintain a fixed flux, and the series field coils *S* increase the flux when the motor slows

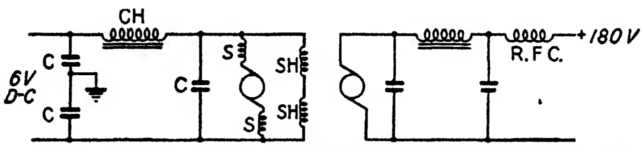


FIG. 152.—Circuit digram of a dynamotor and associated filters.

down, owing to a load on the generator. This increased flux raises the voltage of the generator and compensates for the drop in the voltage due to the reduced speed of the motor. The choke *CH* and the consensers *C* are used as a filter to prevent any disturbance, due to the commutator action, from causing interference in the set. The high-voltage filter in this power supply is also of conventional design.

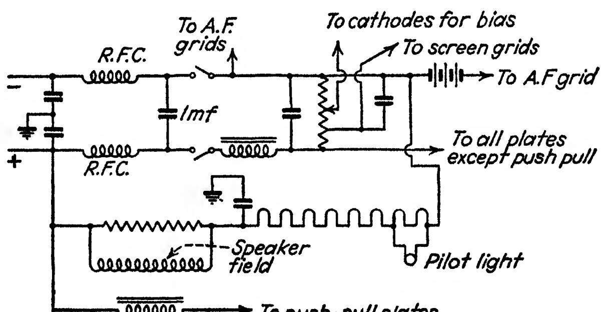


FIG. 153.—Circuit diagram of a d-c power supply illustrating the use of a *C* battery to conserve the plate voltage.

Power Supplies from 115-volt D-C Circuits.—The circuit shown in Fig. 153 is used in the model 645 d-c Stromberg-Carlson receiver. A very efficient r-f line filter is used in the input circuit. The method of obtaining the screen-grid voltage is unusual. A special choke is used to filter the plate supply for the power tubes in order that the maximum amount of the

available voltage may be had on their plates. A portion of the filament current is used to energize the speaker field.

A battery is used to supply grid bias for the a-f tubes in order to use all of the available line voltage on the plates. Figure 154 shows the schematic circuit of the power supply used in the Philco model 48 d-c receiver. It employs a simple capacity line filter and utilizes the speaker field as a choke to filter all of

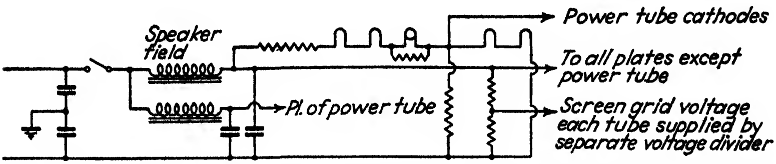


FIG. 154.—Circuit diagram of a d-c power supply showing a method of obtaining screen-grid voltages.

the plate current used in the set except that of the power tube, which has its own choke. The grid bias for each tube is obtained from individual bias resistors, which lower the plate voltage available by the amount of the grid bias.

Figure 155 shows the schematic circuit of the power supply used in the Kolster model K113 d-c receiver. In this circuit, the screen-grid voltage is obtained from a tap in the speaker field and filament circuit. The grid bias for the power tubes is

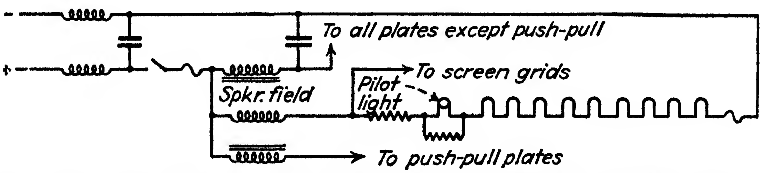


FIG. 155.—Circuit diagram of a d-c power supply illustrating the use of the *IR* drop in the speaker field for screen-grid voltage.

furnished by a battery to avoid lowering the plate voltage on these tubes.

6-volt D-C—115-volt A-C Power Supplies.—Some of the public-address systems are equipped with a power supply arranged for either a 6-volt d-c or 115-volt a-c source. They can, then, be used on picnics, construction jobs, etc., away from the power lines. The addition of the 115-volt a-c source of supply lowers the cost and greatly increases the convenience of

operation when the commercial power is available. Figure 156 shows the schematic diagram of a power supply of this type.

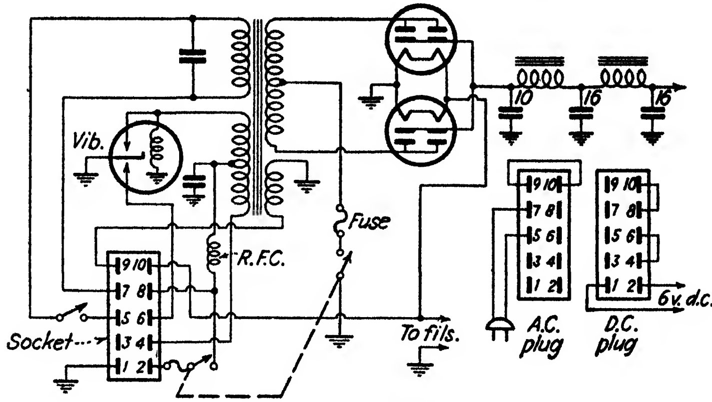


FIG. 156. (*Courtesy A. L. W.*)

A-C D-C Battery Power Supplies.—In order to reduce the cost of operating portable radio sets, some of them have the power supply arranged to use power from either a-c or d-c lighting

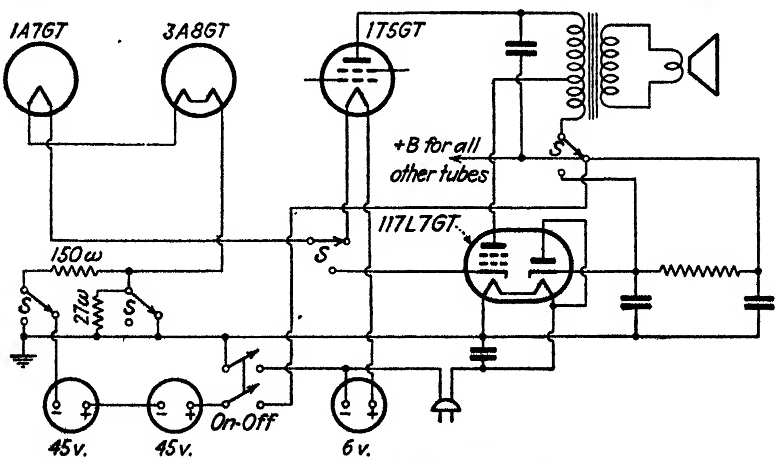


FIG. 157.—An a-c d-c battery power supply.

circuits when they are available or from self-contained batteries. The circuit of a General Electric set of this type is shown in Fig. 157. For long battery life with these sets it is necessary

to use the low-current, 1.4-volt filament-type tubes, but these tubes will not operate with alternating current on the filaments. Many schemes are used to provide d-c filament power for the tubes in these sets. In the diagram shown in Fig. 157 the filaments of the battery-type tubes are put in series and used as part of the cathode bias resistor of the 117L7GT tube. Notice that the 1T5GT battery-type output tube has no filament voltage for a-c d-c operation and that the 117L7GT tube has no heater power on battery operation. The control grids of these two tubes are in parallel but only one works at a time.

The switch *S* is arranged so that it is set for battery operation when the cord is put in the cabinet and changes to a-c d-c operation when the cord is removed.

Voltage Regulation of Power Supplies.—The voltage regulation of a power supply is the percentage of its full-load voltage that the output voltage drops when full load is applied, or

$$\text{Percentage regulation} = \frac{\text{no-load } E - \text{full-load } E}{\text{full-load } E} \times 100.$$

The output voltage of a power supply with good voltage regulation will vary little as the load is increased from zero to full load.

It has already been shown that mercury-vapor rectifiers, bleeder resistors, and choke-input filters tend to give better voltage regulation. In many cases, however, such as in power supplies for vacuum-tube voltmeters and other test equipment, amplifiers whose amplification must be maintained at a very constant value, such as those used in medical research work and similar applications, should be provided with additional means to maintain constant output voltage.

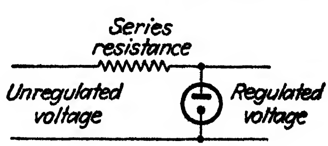


FIG. 158.—Circuit diagram of a voltage-regulator tube.

Voltage Regulator Tubes.—The circuit for any of the regulator tubes, VR75-30, VR90-30, VR105-30, or VR150-30, is shown in Fig. 158. A resistance should always be put between the tube and the unregulated source of power. Its value should be high enough to limit the current through the tube to 30 ma. The 75, 90, 105, and 150 in the tube numbers indicate the value of the regulated voltage that they will provide. If necessary, two or three tubes may be used in series to provide higher output voltages.

If very good regulation is required, the circuit shown in Fig. 159 may be used. This circuit compensates for both load and line variations. The r_p of a triode such as a 45 or 2A3 is used as a regulating resistor. The value of r_p is varied by varying the C bias. The control tube is any one of the sharp cut-off pentode voltage amplifiers such as the 6J7.

In operation the VR75-30 maintains the cathode of the control tube at a fixed potential. The potentiometer R_1 is set to give the grid a negative bias with normal load. If the load increases, the output voltage tends to drop and the voltage between the arm of R_1 and ground decreases in proportion. This increases the difference between the voltage on the grid and cathode of the control tube, increases its C bias, and decreases its plate current. The decreased drop in R_3 reduces the bias on the regulator tube, which reduces its r_p and increases the output voltage.

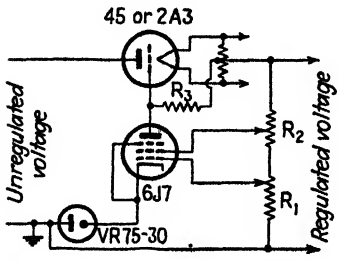


FIG. 159.—Schematic diagram of a voltage-regulator circuit.

Trouble Shooting in Power Supplies.—The most common difficulty in power supplies is faulty condensers. If low voltage or excessive hum is found in a set using electrolytic condensers in the power supply filter, those condensers should be checked first. The electrolytic condensers have many advantages—high capacity in small space, low cost, etc.—but it must be realized that they are not a permanent part of the set, such as the tuning condensers and coils. They should be looked upon in much the same light as the tubes, *i.e.*, subject to periodical replacement, whereas well-designed paper condensers should operate satisfactorily for the lifetime of the set. If there is any indication of corrosion such as discoloration of the cardboard cover due to liquid soaking through from the interior or swelling of the condenser or signs of leakage shown by the formation of scale on the exterior at any point, the condenser should be replaced regardless of whether or not it tests satisfactorily. All these signs indicate that the condenser soon will be bad, and its prompt replacement may save a return call and also more extensive damage. There are several electrolytic condenser testers on the market but, just as in the case of the tube checkers, they do

not pick out *all* bad condensers. For this reason, if any peculiar action, such as hum or other noise or intermittent operation, that does not yield to the ordinary remedies for these conditions is encountered, the trouble may usually be found in a defective electrolytic condenser, which may be either in the set or in the power supply.

In discussing trouble shooting in the power supply, one symptom indicating trouble will be dealt with at a time.

1. Symptom: No voltage, either alternating current or direct current, from the power supply. This clearly indicates trouble in the power transformer. Its appearance or odor will immediately determine whether or not it is burned out. Check the line voltage and the continuity of the plug, cord, switch, and primary. Look for a fuse in the primary circuit in the set.

2. Symptom: Filament and heater voltages normal but no plate voltages. This might possibly be an open circuit in the high-voltage secondary of the transformer but is much more likely to be in the filter or the rectifier tube. If the rectifier tube gets unusually hot, a short circuit is indicated. This will usually be a defective condenser, and if the filter has a condenser input the trouble will usually be in this condenser. Disconnect it and turn the set on. If the rectifier no longer heats excessively and the output voltages return to practically normal values, the trouble has been located. If not, test the condenser connected to the point between the chokes. If this does not clear the trouble, test the other condensers in the filter. It should be noticed that all the plate by-pass condensers are across the output of the power supply. If one of these condensers is defective, it will have the same effect on the voltage as a defective condenser in the power supply itself.

It occasionally happens that a failure of the plate voltage is caused by an open choke coil. The rectifier will not overheat with this difficulty, for it is passing no current at all. A check of the continuity through the filter will locate this difficulty quickly. Chokes seldom burn open. They usually open up owing to corrosion, which as a rule takes place on the leads from the coil to the terminals. Many chokes can be repaired by splicing and reconnecting the leads to the terminals.

3. Symptom: Excessive hum. Check paper filter condensers for open circuits by charging them at their rated voltage and then shorting the terminals after the charging voltage has been

removed. An open condenser will not give a spark. Electrolytic condensers are difficult to check for open circuits. If one is suspected, check it by replacing it with a new one.

Excessive hum is also occasionally caused by an open circuit in one-half of the high-voltage secondary of the power transformer of a full-wave rectifier. When a single faulty condenser is found in a condenser bank, the problem always arises as to whether the whole bank should be replaced or whether the faulty condenser can be cut loose and replaced with a single section. Many things should be considered to make the proper decision. If the difficulty is in a high-priced set, the entire bank should be replaced. This is the best solution, because if one of the sections in a bank is defective it is very probable that others will soon break down. However, if the set is rather old or other considerations indicate that the owner will object to the expense of a complete condenser bank, a separate section can be mounted near the bank and connected in place of the defective section.

An attempt to melt the compound in the can to remove the defective section and replace it will usually result in ruining several more sections rather than in making an improvement.

Hum may also be caused by a full-wave rectifier having unequal current from the two plates. This might be caused by loss of emission on one of the cathodes or one side of the filament, or it might be due to the unequal spacing of the elements in the tube, due to rough handling, etc.

Checking for Hum with the Cathode-ray Oscillograph.—At first thought, it might seem that the cathode-ray oscillograph would be an ideal instrument to investigate the cause of hum, but, when it is realized that the sensitivity of the usual oscillograph is about 2 volts per inch (height of the image), it will be seen that a hum voltage which would be entirely too high for the satisfactory operation of a high-gain amplifier would produce such a small deflection even with the use of the vertical amplifier that it could not be detected. In fact, the hum voltage would have to be so large before it could be detected by the oscillograph that it could be caused only by such extremely faulty components that could easily be found by the use of simpler equipment. A pair of headphones in series with a 0.1-mf. high-voltage condenser makes a satisfactory means of locating hum. But even this device is not sensitive enough to test for hum in a power pack

supplying the preamplifier of a high-gain public-address equipment. This is due to the fact that the hum introduced in the first stages of the amplifier may be inaudible, but, owing to the great amount of amplification between this point and the loud-speaker, the hum may be very troublesome in the loud-speaker. Unless an amplifier that is entirely free from hum is available (this usually means a battery-operated amplifier) to amplify the hum voltage to an audible level so that a cathode-ray oscillograph or a pair of headphones can be used, the best way to eliminate hum is to try the effect of increasing the condensers in the power supply, especially the last one, or to increase the efficiency of the plate-supply filter in the circuit of the first tube by increasing the size of the resistor, or condenser, or both.

In high-gain amplifiers, the input transformer is often guilty of picking up hum due to the field surrounding the power transformer or the filter choke. If the hum stops, or is very much lessened, when this transformer is disconnected from the first tube, this type of pickup is indicated. Try turning the transformer in various positions. If this is not entirely successful, increased shielding should be used. The author has found that a shield made of several layers of about 20-gauge sheet iron, so that the final thickness was approximately $\frac{3}{8}$ in., completely surrounding the transformer will cure very difficult cases.

REVIEW QUESTIONS

7-1. Show labeled diagrams indicating the output of full-wave and half-wave rectification.

7-2. Name the parts of a power supply.

7-3. Show a diagram of a half-wave power supply with condenser input to the filter.

7-4. Show a diagram of a full-wave power supply using a mercury-vapor rectifier and a choke-input filter.

7-5. What is the purpose of the filter?

7-6. What effect does the presence of an input condenser have on the voltage output of a filter?

7-7. What effect does the presence of an input condenser have on the hum output of a filter?

7-8. What are the advantages and disadvantages of bleeder resistors?

7-9. What is meant by three-phase current?

7-10. Show a diagram of three power transformers connected to a three-phase circuit with the primaries delta- and the secondaries star-connected.

7-11. Show a diagram of a full-wave three-phase power supply.

7-12. In what way would the filter for a filament supply on a three-way power supply differ from the high-voltage filter?

7-13. In a power transformer, what determines the size of the core? The wire size on the high-voltage winding?

7-14. What is meant by the expression "turns per volt"?

7-15. Give five hints or precautions on transformer winding.

7-16. How can you determine when two transformer coils are properly connected in series adding?

7-17. Show a transformer circuit for raising the line voltage.

7-18. Show a circuit of an a-c d-c power supply.

7-19. What precaution must be taken when an a-c d-c radio is used on a d-c circuit?

7-20. Explain why an a-c d-c radio usually has more volume on alternating current than on direct current.

7-21. How can rectifiers in a-c d-c sets be protected from excessive current immediately after the set is turned on?

7-22. Show a circuit diagram of a full-wave voltage doubler circuit.

7-23. Show a circuit diagram of a half-wave voltage doubler.

7-24. Explain the action of a full-wave voltage doubler circuit.

7-25. Explain the action of a half-wave voltage doubler circuit.

7-26. Show a circuit diagram of a nonsynchronous power supply.

7-27. What is the purpose of the buffer condensers in a vibrator power supply?

7-28. (*a*) What effect will a buffer condenser with too little capacity have on the operation of a vibrator power supply? (*b*) What will be the effect of one too large?

7-29. What is the best method of checking the operation of a vibrator?

7-30. Show the circuit of a shunt-connected d-c motor.

7-31. Show the circuit of a compound-connected d-c motor.

7-32. Show the circuit of a universal-type motor.

7-33. Discuss the speed load characteristics of series, shunt, and compound motors.

7-34. Name the principal parts of a d-c motor.

7-35. How can the speed of a d-c motor be increased?

7-36. What precaution should be used when driving a d-c motor at overspeed?

7-37. What is meant by counter electromotive force or counter e.m.f.?

7-38. How can the speed of a d-c motor be decreased?

7-39. Why is it necessary to use resistance in series with large motors while starting?

7-40. What care should be taken of ring-type oiling systems?

7-41. What care should be taken of ball bearings?

7-42. What maintenance care should be taken with motor brushes?

7-43. Give the procedure for fitting brushes.

7-44. Describe the procedure for undercutting the mica on a commutator.

7-45. How is the voltage output of a generator controlled?

7-46. What is a dynamotor?

7-47. Give the formula for the voltage regulation of a power supply.

7-48. Show the circuit diagram of a voltage-regulator tube.

7-49. What trouble will usually be found in power supplies when servicing radios?

7-50. What indications will point to a blown or shorted filter condenser?

7-51. How can a power supply for a radio or public-address system be checked as a source of hum?

CHAPTER VIII

SYSTEMS OF DEMODULATION OR DETECTION

The diode under the name of Fleming valve was the first vacuum-tube detector to be used. That was before the introduction of the grid to the vacuum tube. The *C* bias detector was next used. It was followed by the grid-leak grid-bias detector because of its greater sensitivity. At that period the r-f amplifiers were not yet perfected and the signal had to be fed directly into the detector circuits. The distance over which reception could be achieved was limited by the sensitivity of the detector. Later, when r-f amplification could be successfully used, the need for a sensitive detector no longer existed. The problem then was to find a detector that would not "block up" and stop reception on strong signals. This brought about the return of the *C* bias detector under the new name of power detector. This detector had to be discarded when the transmitters changed to a high percentage of modulation because of its square-law characteristics. Under modern conditions the only satisfactory detector is one having linear characteristics.

The detectors used in frequency-modulated radios differ so much from those used in amplitude-modulated radios that they cannot be grouped with the amplitude-modulated detectors. They will be discussed in Chap. XIII entitled "Frequency-modulated Receivers."

The detectors used in modern amplitude-modulated radio receivers may be grouped into two classes: the square-law detectors and the linear detectors. The square-law detectors are so called because their audio output voltage is proportional to the square of the r-f input voltage. This means that, if the audio output voltage is measured for a certain r-f input and then the input is doubled, the output will be four times its original amount. Likewise tripling the input voltage will give nine times the output. The output of linear detectors is directly proportional to the input. This means that doubling or tripling the

input will double or triple the output. The distortion produced by the square-law detectors depends, among other things, on the percentage of modulation of the received signal and increases with the percentage of modulation. Since modern transmitters operate at high percentages of modulation, these detectors are unsatisfactory for the distortion reaches a maximum of 25 per cent with 100 per cent modulation. Distortion of 5 per cent or more is readily noticeable.

Square-law Detectors.—Both the *C* bias and the grid-leak condenser detectors are square-law detectors. The grid-leak grid-condenser detector is normally the more sensitive of the two. Its sensitivity is increased by increasing the value of the grid leak. However, increasing the value of this resistor prevents strong signals from leaking off the grid rapidly. The signal voltage then piles up on the grid making it more and more negative until the operation of the tube is blocked. This is called grid "blocking." The *C* bias detector is not so sensitive but it can handle a much larger signal without blocking up.

C Bias Detector.—The schematic diagram of a *C* bias detector is shown in Fig. 160.

The *C* bias is adjusted so that the operating point *A* is at the point in the curve where the sharpest curvature occurs. The signal voltage is represented by *B*. This voltage is modulated, which simply means that its amplitude varies in accordance with the audio frequency fed into the transmitter. A line drawn through the tips of the r-f waves is called the "envelope." This is indicated at *C*. The fluctuations of the plate current, due to the varying grid bias, are shown by *D*. Note that the plate current increases more during one half cycle than it decreases in the other half cycle. This excess current in one direction has the same effect on the phones or audio transformer as the pulsating current shown at *E*. This current wave will have the same shape as the envelope of the input signal. The shape of the input signal envelope is determined by the audio signal fed into the transmitter, and so the current wave shown at *E* will be an exact reproduction of the original wave picked up by the studio microphone provided that there is no distortion in either the transmitter or receiver and no interfering signals. Notice that the average plate current increases when a signal is applied to the tube. The stronger the signal, the greater will be the increase.

This fact can be used in lining up r-f amplifiers by putting a d-c milliammeter in the detector plate circuit and making adjustments to obtain the highest possible reading. The maximum reading is the correct adjustment for *C* bias detectors only.

This detector produces distortion by introducing the second harmonic into the output. A r-f by-pass is always used with this detector. Often it is simply a condenser as shown in Fig. 160;

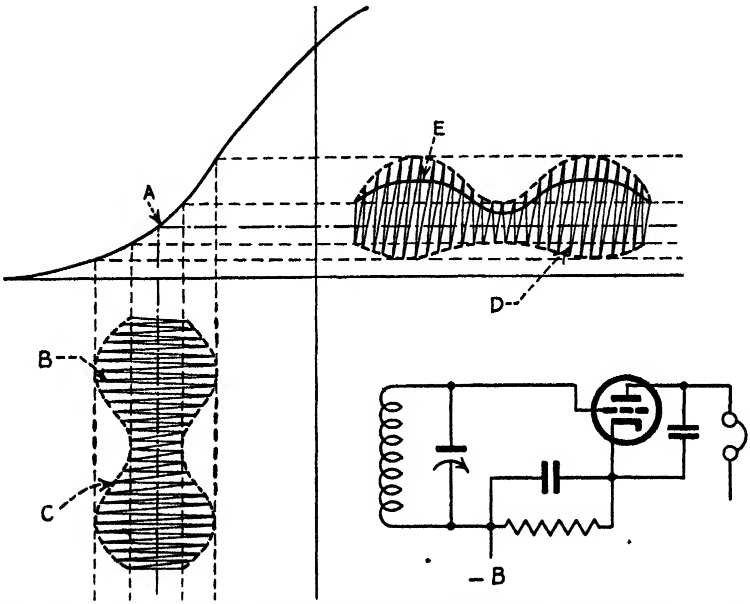


FIG. 160.—*C* bias detection obtained by operating on the curved portion of the characteristic curve.

however, if the r-f or i-f input to the detector is low in magnitude, a high-pass filter (discussed in Chap. IX) is often used.

Grid-leak Grid-condenser Detectors.—Figure 161 gives the schematic diagram of a grid-leak grid-condenser detector and illustrates what happens when a signal is applied to the input of a grid-leak condenser detector.

When the grid goes positive, it attracts electrons from the cathode, and current flows through the grid leak. The *IR* drop produced across the grid leak puts a negative bias on the grid, which reduces the plate current. The circuit including the grid, cathode, grid leak, and secondary of the r-f transformer is

exactly like that of a half-wave rectifier. The grid of the detector takes the place of the plate of the rectifier, and the grid leak acts as the bleeder resistance. For best reception, the straight portion of the characteristic curve should be used. This is usually accomplished by choosing the plate voltage so that the straight portion of the curve will occur at zero grid bias. Too

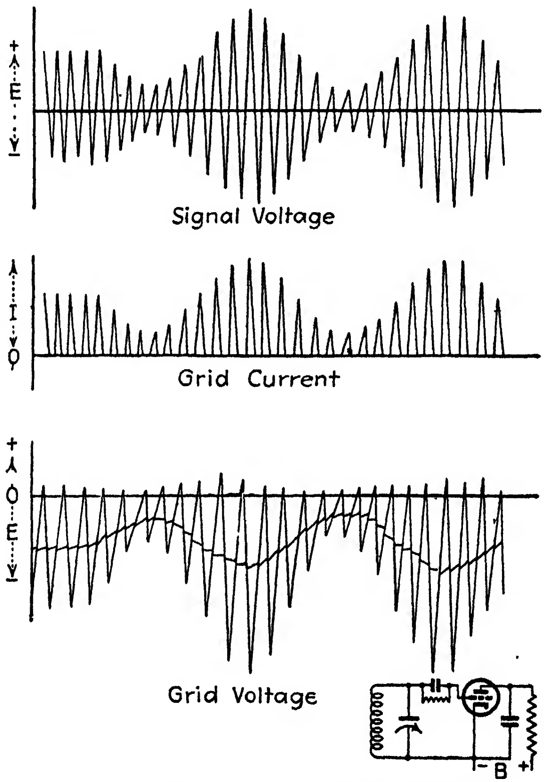


Fig. 161.—Grid-leak grid-condenser detection.

high a voltage on the plate makes the signal on the grid relatively ineffective, and too low a voltage on the plate brings the operation on the curved portion of the characteristic, which also prevents proper detector action. The grid condenser must be large enough to pass the radio frequencies and, at the same time, small enough to offer a high impedance to the audio frequencies across the grid leak.

Linear Detectors.—By increasing the grid-bias resistor until the plate current is nearly at cut-off and by using a very high resistance in the plate circuit, the grid-bias detector can be made to have linear characteristics. Diodes are also linear detectors except for very low-input voltages.

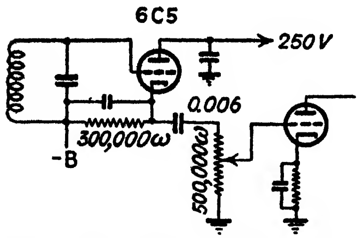


FIG. 162.—Circuit diagram of a recent type of linear detector.

The term "linear detector" is used because the graph obtained by plotting the audio output voltage against the input voltage is a straight line, or, to use the technical term, it is "linear."

Another type of linear detector has been suggested. This is a plate circuit detector with the load in the cathode circuit as shown in Fig. 162. This detector has several advantages. It does not load up the tuned circuit feeding it and so is adaptable to tuned-radio-frequency (t.r.f.) receivers. It is said to be practically as linear as the diode detector. Its main advantage, however, is in the fact that it can handle even a higher degree of modulation than the diode without distortion. The main disadvantage of this type of detector lies in the fact that it does not provide a.v.c. voltage. Since the cathode potential is much above ground, there is a possibility of hum from this source.

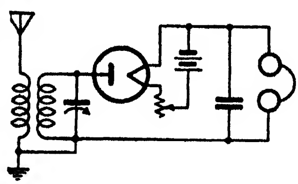


FIG. 163.—Schematic diagram of a Fleming valve detector.

Diode Detectors.—The original vacuum-tube detector was a diode, the old Fleming valve. The schematic circuit is shown

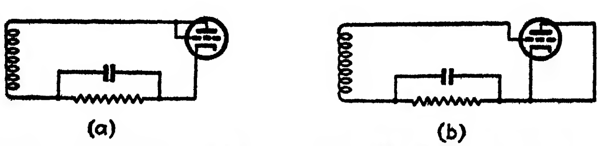


FIG. 164.—Circuit diagram of a triode used as a diode detector.

in Fig. 163. Any three-element tube can be used as a diode detector, as shown in Fig. 164. In some circuits, the plate is connected to the grid, whereas in others it is connected to the

cathode. The latter connection uses the plate as a shield. Most of the diodes are combined with either a triode or a pentode in the same bulb. The diode portion of the tube is connected and operates exactly as an 80 or 81 rectifier operates, as shown in Figs. 165 to 168. Figure 165 gives the conventional circuit of an 80 rectifier. Figure 166 shows the same circuit rearranged to demonstrate its similarity to Fig. 167. In all three arrangements, a pulsating d-c voltage will be produced across the resistance A. In Fig. 165, due to incomplete filtering, there would be a hum voltage of 120 cycles across the resistance A. In a half-wave circuit the frequency would be 60 cycles. In other words the frequency of the hum voltage with a half-wave rectifier is the same as the a-c supply frequency. The hum voltage with a full-wave rectifier is always twice the a-c supply frequency. This rule applies to radio or intermediate frequencies as well as to power-line frequencies. There will be, then, a voltage of either the intermediate frequency or twice the intermediate frequency across the diode-load resistor A. A by-pass condenser is always connected across this resistor to by-pass these frequencies but, if it is made sufficiently large to be completely effective, it will also by-pass the higher audio frequencies which are also present.

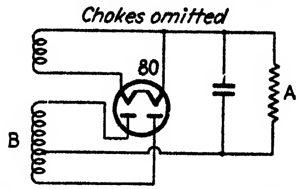


FIG. 165.—Circuit diagram of a power-circuit rectifier.

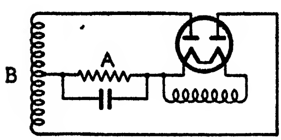


FIG. 166.—Circuit diagram of a power-circuit rectifier rearranged to show its similarity to a diode-detector circuit.

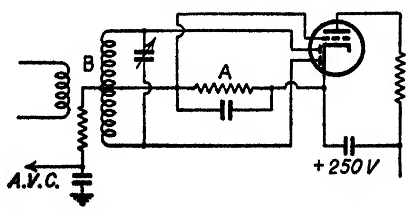


FIG. 167.—Circuit diagram of a full-wave diode circuit with a diode-biased audio amplifier.

And now to go back to the voltages across the resistor A. In Fig. 165 the d-c voltage across A will rise and fall with the a-c voltage in the winding B. This must also be true in Fig. 167.

But the i-f voltage in *B* of Fig. 167 is modulated—in other words is varying at audio frequency. The varying voltage across *A* is fed into the audio amplifier.

The circuit shown in Fig. 167 uses what is known as "diode bias" on the grid, because the only grid bias is the d-c voltage developed across the load resistor *A* by the signal. This circuit is not recommended for use with high voltage on the plate unless resistance coupling is used, for with no signal on the diodes, there will be no bias on the tube, and the plate current will be excessive except when it is limited by the plate resistor. A method of maintaining a fixed bias on the grid is shown in Fig. 168, which also shows the diodes in a half-wave circuit.

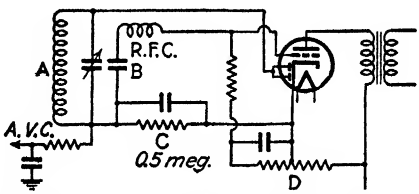


FIG. 168.—Circuit diagram of a half-wave diode circuit with a cathode-biased audio amplifier.

The full-wave circuit gives a maximum of fidelity; but, owing to the necessity of center-tapping the coil, only half of the voltage can be used. The half-wave rectifier circuit is slightly inferior in fidelity, but it has the advantage of full output voltage.

Regenerative Detectors.—The modern use of these detectors is confined to short-wave sets and adapters. For modulated, continuous-wave reception, these detectors can be adjusted for extreme sensitivity. This is due to the almost total neutralization of the resistance in the tuned circuit by the energy fed back into it from the plate circuit. For continuous-wave telegraphic signals, the detector can be made to generate oscillations that combine with the incoming signal and create an audible signal. A more detailed explanation of the theory of this action will be given in Chap. XII on "Superheterodynes."

Figure 169 gives the schematic diagram of a regenerative detector. There are several ways of controlling the regenerative effect. The feed-back coil can be mounted on pivots so that the coupling between it and the tuning coil can be controlled by rotating the coil. This method has two disadvantages: the

control is rather hard to adjust correctly and the field of the feed-back coil is sprayed over the r-f coils as it is rotated. This has a tendency to produce uncontrollable oscillation.

The second method consists of using a fixed tickler coil, usually wound on the same form as the tuning coil, and by-passing it with a rheostat. The setting of the rheostat determines the amount of current passing through the coil and, therefore, the feedback. This method gives a much less critical control of regeneration.

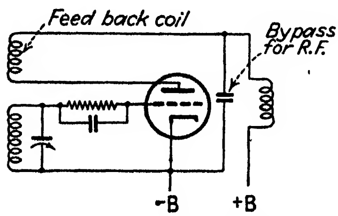


FIG. 169.—Circuit diagram of a regenerative detector with tickler feedback.

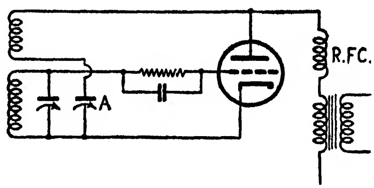


FIG. 170.—Circuit diagram of a regenerative detector with throttling-condenser control of feedback.

Figure 170 shows the schematic diagram of a third method of controlling regeneration by the use of what is known as a "throttling condenser." This condenser is marked *A* in the diagram. Smoother regeneration can be achieved by reducing the size of the grid leak and grid condenser; however, this also reduces the sensitivity.

REVIEW QUESTIONS

8-1. Name the two major types of detectors.

8-2. What is meant by a square-law detector?

8-3. What is a linear detector?

8-4. How can the sensitivity of a grid-leak grid-condenser detector be increased?

8-5. For what type of signals is a *C* bias detector especially adapted?

8-6. Describe the operation of a *C* bias detector.

8-7. What is the special advantage of a grid-leak grid-condenser detector?

8-8. Describe the action of a grid-leak grid-condenser detector.

8-9. Describe the operation of the diode detector.

8-10. Describe in detail the voltages on the diode-load resistor.

8-11. Show a diagram of a grid-leak grid-condenser detector.

8-12. Show a diagram of a *C* bias detector.

8-13. Show a diagram of a half-wave diode detector with a diode-biased amplifier.

8-14. What is the main objection to diode-biasing an amplifier and how is it partly overcome?

8-15. Show a diagram of a full-wave diode detector with a self-biased audio amplifier. Do not use the diode-load resistor for the volume control.

8-16. Show a diagram of a regenerative detector circuit.

CHAPTER IX

VOLUME, TONE, AND FREQUENCY CONTROL

In order to be satisfactory, a volume control should be capable of reducing the volume of a powerful local station to almost inaudibility and, at the same time, should allow the use of the full gain of the set on weak distant stations. It should be placed in the set so that none of the tubes is overloaded by the strong local signals; otherwise distortion will result. Many of the controls in older sets cannot meet this requirement, and excessive volume and serious distortion cannot be avoided on powerful local stations. These sets were built before the high-powered stations were in existence. The first step taken to eliminate this difficulty was the use of dual controls, which cut the volume in two different places and usually by two different methods. There are several variations of this scheme. One control usually varied a resistance across the antenna coil. The second control varied either the control-grid or the screen-grid voltage.

Some sets have a "local-distance switch" that reduces the r-f voltage by reducing the coupling between the antenna and the first tube or between two of the tubes. The control designated as the "volume control," then, alters either the control-grid or the screen-grid voltage. Controls of this type usually carry direct current and because of that soon become noisy. They are usually wire wound. If an attempt to control the volume is made by increasing the control-grid voltage nearly to the cut-off point of a screen-grid tube, distortion will occur due to the curvature of the characteristic in this region. Practically all the modern radio receivers use the grid-bias method of volume control but avoid the difficulty just mentioned by the use of variable-mu tubes. These tubes require a much higher grid bias to run them to cut-off than the standard type. The grid bias can therefore be varied over a much wider range without producing objectionable distortion. In the smaller receivers, the grid bias is controlled manually by using a variable C bias resistor. This

resistor is often made a part of a bleeder circuit across the power supply so that the current through it will be increased by the amount of the bleeder current. Otherwise, the resistor would have to have a much wider range of resistance because of the very low plate current of this type of tube. In the more elaborate receivers, the bias is controlled automatically. When a.v.c. is used, a control is incorporated in the audio amplifier to adjust

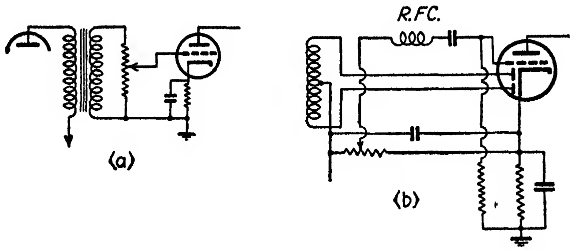


FIG. 171.—Audio-frequency volume controls. Diagram (*a*), shunt-type control; diagram (*b*), the diode-load resistor used as a volume control.

the volume level coming from the speaker. Diagram (*a*) in Fig. 171 illustrates a control of this type. The diode load resistor can also be used as a volume control as shown in diagram (*b*) in Fig. 171.

Acoustically Compensated Volume Controls.—When the ordinary volume control is adjusted for low volume, the middle of the a-f band seems to be amplified more than the higher and lower frequencies. This effect is caused by the characteristics of the human ear. At low volume, the ear is relatively insensitive to the high and low frequencies. To compensate for this peculiarity, the circuit shown in Fig. 172 is sometimes used. The circuit *LC* is tuned to the middle of the audio band and attenuates these frequencies more than the higher and lower frequencies at the low-volume settings of the control. This circuit must be used with an a.v.c. circuit to maintain a constant r-f input to the detector.

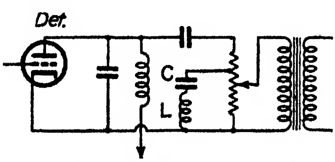


FIG. 172.—Acoustically compensated volume control.

Automatic Volume Control.—There are two important advantages gained by having the volume controlled automatically; (1) elimination, or reduction, of the effects of fading on the

output; (2) freedom from sudden bursts of sound when a local signal is tuned in inadvertently when searching for some distant station. Both of these advantages add much to the enjoyment of radio entertainment.

Automatic volume control can be used only in sets using tubes whose amplification constant can be varied over a wide range by a change in the grid bias. The supercontrol grid or variable-mu tubes are of this class and are universally used with a.v.c. The variable grid bias is obtained by rectifying at least a part of the voltage supplied to the detector and passing the resulting current through a resistor. The *IR* drop in this resistor is then used as the grid bias on the controlled tubes. These circuits are shown in Figs. 167 and 168. In some circuits, additional bias is supplied by a resistor in the cathode circuit of the variable-mu tubes. As the r-f voltage supplied to the rectifier rises and falls, owing to a variation in the received signal, the d-c voltage across the resistor will also rise and fall. It will be seen, then, that a strong signal producing high r-f voltages will also produce a high grid bias on the controlled tubes, which will lower their amplification constant and reduce the signal reaching the rectifier. In this manner, the input to the detector is maintained substantially constant.

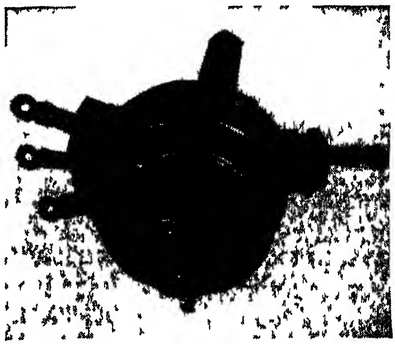


FIG. 173—An acoustically compensated volume control.

At this point, the voltage across the diode-load resistor should be studied more carefully. This voltage is the result of rectifying the output of the i-f amplifier. The voltage is fundamentally the intermediate frequency; furthermore, this voltage is not constant because it is modulated at audio frequency and also the incoming signal strength is not constant, so the i-f voltage will also vary because of this condition. In a power supply circuit, it is well known that a variation in the a-c voltage will cause a similar variation in the d-c voltage. In a like manner, the variations in the i-f voltage cause a variation in the d-c voltage across the load resistor. The voltage across this resistor

then varies with the audio signal, and if it is not filtered it will vary at the i-f frequency, which corresponds to the 60 cycle in a power supply. The i-f frequency is nearly all filtered out immediately by putting a condenser across the resistor which has a very low impedance to the i-f frequency and therefore effectively by-passes it. Too large a condenser in this position will also by-pass the higher audio frequencies and limit the frequency response of the set. High-fidelity sets require a smaller condenser at this point because of their extended h-f range. The audio frequencies are tapped off through a condenser, as described under "Detectors" (see page 176). If this same pulsating a-f current is used as a *C* bias on the r-f and i-f stages, the pulsations will modulate the carrier and cause howling and distortion. To avoid this effect, resistance-capacity filters are used. These consist of a high resistance in series with the line and condensers across the line. The value of these components is critical.

Time-delay Circuits.—The combination of a resistor in series with the line and a condenser across the line forms what is known as a "time-delay circuit." These circuits are to be found in many places in modern radio circuits. In the a.v.c. circuits, the voltage taken from the diode-load resistor is pulsating both at intermediate frequency and at audio frequency. If this i-f voltage were allowed to reach the grids of the i-f amplifier tubes, an excellent regenerative circuit would result, which would have a great tendency to oscillate. If the audio frequency were fed back, it would modulate the intermediate frequency and cause serious distortion. But with a condenser across the line, the voltage supplied to the grids of the controlled tubes cannot increase until the condenser is charged. If there is a resistor in series with the line, the charging current of the condenser is limited by it and the condenser takes longer to become fully charged. The time is always longer than the time required for one cycle of the lowest frequency, and so the voltage across the condenser does not rise and fall with the voltage from the diode-load resistor.

Time Constant.—The product of the resistance in megohms and the capacity in microfarads will give the effective time constant in seconds. In an a.v.c. circuit, if the time constant is too large, *i.e.*, if the condenser or the resistor or both are too large, a sudden

application of a higher voltage to the circuit such as would occur when a strong station was tuned in would not be immediately applied to the grids of the controlled tubes and they would still have a high amplification factor. This means that the increased volume would reach the loud-speaker. As soon as the condenser had time to charge up, the volume would be reduced to normal. On the other hand, if a strong station had been tuned in for some time and then the dial shifted to a weak station, it might be passed over entirely, because the amplification was still low owing to the fact that the condenser had not had time enough to discharge and thereby reduce the voltage on the grids. On the other hand, if the time constant is too small, *i.e.*, if the condenser or the resistor is too small, the gain in the amplifier will follow the modulation, which will result in howling due to feedback and distortion due to the audio frequency modulating the i-f signal.

A tuning indicator is almost always supplied with sets using a.v.c. because the volume will be nearly constant over a band of frequencies owing to the action of the a.v.c., which tries to maintain a constant signal input as the signal voltage fluctuates.

Nearly all the sets having a.v.c. also have incorporated in them some means of eliminating the noise when tuning between stations. These circuits are known under various names, such as "quiet automatic volume control" (q.a.v.c.), "noise-suppression control" (n.s.c.) or simply "noise-suppression circuits." These circuits are necessary because the a.v.c. allows the set to reach maximum sensitivity when no carrier wave is being received. In this condition, the amount of static reproduced is excessive. The noise-suppressor circuits shut off the output of the set until some fixed value of signal is received. Examples of these circuits are explained later in this chapter.

Short-circuiting Rectifier.—An unusual type of rectifier used in some of the a.v.c. circuits is shown in Fig. 174. It is known as a short-circuiting rectifier because it puts a short circuit across the output during the half cycle when the current is in the wrong direction. In Fig. 174 the upper diode plate is used as a detector. The detector circuit is incomplete. The lower diode acts as the short-circuiting rectifier. When the signal voltage coming through the 110-mmf. condenser is positive, the lower diode plate is positive and plate current can flow. This practically

shorts out the two resistors in parallel with the diode plate-cathode circuit. When the diode plate is negative, no current can flow through it; consequently, a voltage builds up across the two resistors. The grounded end of the resistors will be positive. In this particular circuit more negative voltage was available than was required for the a.v.c. so the resistors were tapped at the proper point. This point would be negative in respect to ground.

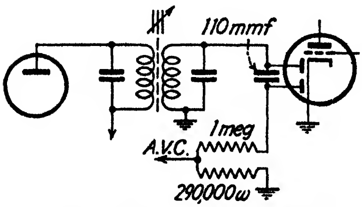


FIG. 174.—A short-circuiting rectifier circuit.

A.V.C. Circuits Taken from Sets in Production.—The circuit of a simple a.v.c. is shown in Fig. 175. Half-wave rectification is used. The d-c voltage appears across the resistor R. The condensers C and C_1 with the resistor R_1 form an r-f filter, whereas R_2 and C_2 form an a-f filter. Both these filters smooth out the voltage supplied to the grids of the controlled tubes. The audio frequency is fed through C_3 and R_4, which is the manual volume control. In this circuit, the r-f and i-f amplifier tubes are controlled. The first detector is not included. The resistor R_3 maintains a fixed bias on the controlled tubes, which limits their plate current to a safe value when no signal is present.

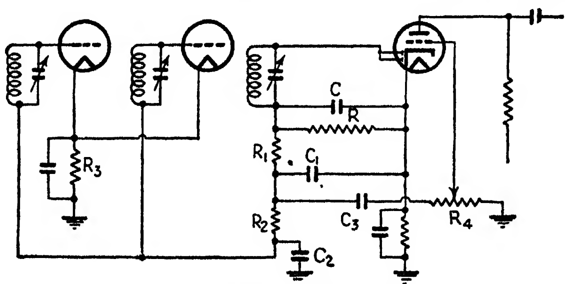


FIG. 175.—Circuit diagram of a simple a.v.c. circuit.

In the Stromberg-Carlson No. 60 receiver circuit, shown in Fig. 176, the pentode section of a 6B7 is used as an i-f amplifier, which feeds the diode portion of the tube. The direct current and the a-f voltages appear across the resistor R. The manual volume control is exactly like the control described in Fig. 175. C, C_1R_1, and C_2R_2 are resistance-capacity filters to keep the

intermediate frequency out of the a.v.c. control. If any of the i-f voltage was allowed to remain in the control line, it would feed back energy into the input of the i-f amplifier and would be almost certain to cause howling.

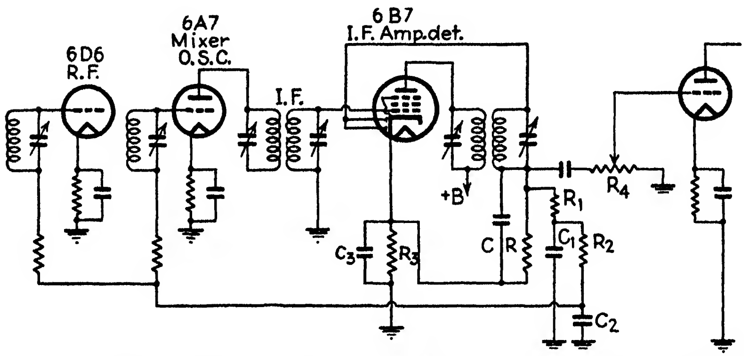


FIG. 176.—Circuit diagram illustrating the use of a duodiode-pentode tube as an i-f amplifier and detector.

A variation of a.v.c. known as "automatic gain control" (a.g.c.), used in the Wurlitzer model SR 133, is shown in Fig. 177. Several other receivers have a.v.c. circuits similar to this.

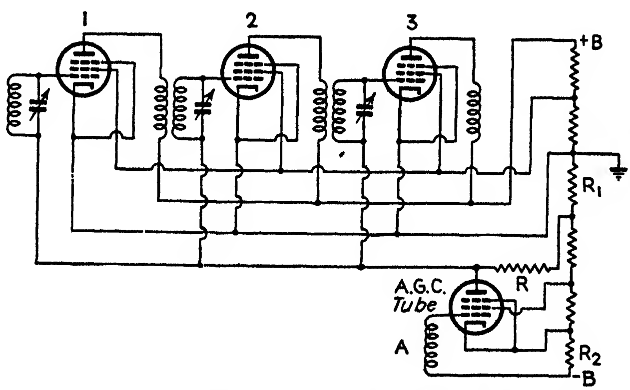


FIG. 177.—Circuit diagram of an unusual type of a.v.c. circuit.

The power supplies for the a.g.c. tube and the controlled tubes are in series, so that the control grids of the controlled tubes are at the same potential as the plate of the a.g.c. tube when no signal is being received. The grid of the a.g.c. tube receives its

signal from the coil *A* that is wound on the i-f transformer supplying the second detector. The grid voltage on the a.g.c. tube, due to the drop in R_2, is such that it is beyond cut-off until a predetermined signal voltage appears in the coil *A*. When this occurs, the tube draws plate current, which causes a voltage drop in the resistor *R*. This voltage aids the voltage drop in resistor R_1 and increases the bias on the controlled tubes. This decreases their amplification constant, resulting in a smaller signal in the coil *A*, which, in turn, shuts off the plate current of the tube, and the process is started all over again.

An example of the use of a single tube for many purposes is shown in Fig. 178. The 6B7 tube is used to amplify both

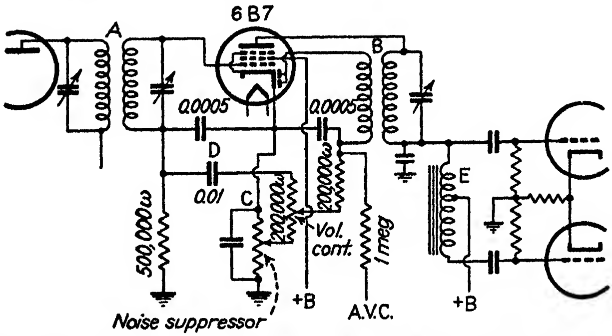


FIG. 178.—Circuit diagram illustrating the use of a single tube as an i-f amplifier, detector, audio-frequency amplifier, and noise suppressor.

intermediate and audio frequencies, as a detector, noise suppressor, and a.v.c. This circuit is from the Emerson model 678 auto-radio.

The signal from the i-f transformer *A* is impressed on the grid of the 6B7, the output of which feeds into the primary of the transformer *B*. The secondary of this transformer feeds the diodes. The a-f voltage is distributed "across" the 200,000-ohm fixed resistor, the 200,000-ohm volume control, and that portion of the noise suppressor above the movable arm. The portion of this voltage appearing between the arm of the volume control and the point *C* is reflexed back to the control grid through the condenser *D*. The a-f output of the tube then appears across the upper part of the auto-transformer *E*, which induces a voltage in the lower portion of the proper polarity to supply the grids of the push-pull output tubes.

The plate current and the current from the diodes flowing through the noise-suppression potentiometer make the arm of this device negative in respect to the cathode. The potential on the arm is carried up through the volume control, the 200,000-ohm resistor, and the secondary of the transformer B to the diode plates. The diode plates, therefore, are negative in respect to the cathode, and no current can flow from them to the cathode until the signal voltage is in excess of the bias on the diodes. This bias can be regulated by adjusting the noise-suppressor potentiometer.

Noise-suppression Circuits.—Figure 179 shows one of the many noise-suppression circuits. When a signal is put on the

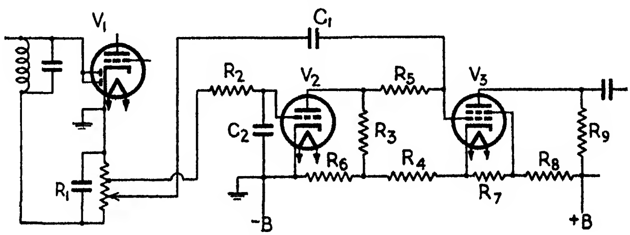


Fig. 179.—Circuit diagram of an n.s.c.

duodiode tube V_1, a d-c voltage modulated with audio frequency appears across R_1. Part of this voltage is fed to tube V_3 through the condenser C_1. Some of the voltage is also fed into tube V_2, through R_2. If the signal on tube V_1 is of sufficient strength, the d-c voltage from R_1 applied to the grid of V_2 will run this tube beyond its cut-off point and no plate current will flow in R_3. With no IR drop in R_3, the only bias on tube V_3 is the drop through R_4, which is the normal C bias resistor. Tube V_3 then amplifies the signal coming through C_1 in the ordinary way.

In case the signal on V_1 is too weak to produce sufficient voltage across R_1 to run V_2 beyond cut-off, the IR drop in R_3, due to the plate current of V_2, will run V_3 beyond cut-off and prevent it from operating.

The combination of R_2 and C_2 is another example of a time-delay circuit. Sudden bursts of static do not last long enough to charge the condenser and thereby stop the plate current of V_2. Any station carrier that is tuned in will hold the voltage on the grid of V_2 so that C_2 charges up to a voltage that will run V_2 to cut-off.

R_3, R_5, and R_6 are the resistors that mainly control the point at which the noise-suppression circuit ceases to function. It is important to have this circuit released before the signal is strong enough to cause the a.v.c. to cut it down; otherwise the noise-suppression circuit will never let go.

Trouble Shooting in Automatic-volume-control Circuits.

If the difficulty is no a.v.c. voltage:

Check the tube.

The diode-load resistor may have very low value.

The by-pass condenser across the load resistor may be shorted.

The a.v.c. line or one of the series filter resistors in it may be open.

If the difficulty is low a.v.c. voltage:

Check the tube.

The resistance of the diode-load resistor may be less than normal.

The by-pass condenser across the load resistor may be leaky.

One of the condensers between the a.v.c. line and ground may be leaky.

If the difficulty is excessively high a.v.c. voltage:

The resistance of the diode-load resistor may be too high.

If the difficulty is oscillation or howling:

The intermediate frequency is being fed back into the amplifier.

Check the a.v.c. line by-pass condensers for opens and the resistors for shorts. It is a good plan to check the condensers when they are hot, for the difficulty may not be apparent when they are cold.

Since the resistances used in the a.v.c. circuits are very large, the condensers associated with them must be practically perfect. The slightest leakage in any of these condensers will surely cause trouble.

As variable-mu tubes age, the cut-off point approaches zero C bias. Under this condition, the a.v.c. voltage forces the tube beyond cut-off and bad distortion results. So far no commercial tube testers have incorporated a method of checking for this difficulty. The easiest method of testing for this difficulty is to change all the tubes that are controlled by the a.v.c.

Tone Controls and Tone Compensation.—There are two main types of tone controls. One type is used to compensate for deficiencies in the circuit. This type is usually fixed. The

other type is used to adjust the output of the radio set or amplifier to meet the owner's preferences or the acoustics of the room or auditorium.

The whole theory of tone compensation is based on the formulas for inductive and capacitive reactance. Inductive reactance X_L equals $2\pi fL$. Since all these quantities 2, π, f, and L are multiplied together, increasing any one of them will increase the product, or X_L. This shows that the inductive reactance increases as the frequency f increases.

The formula for the capacitive reactance is $X_c = \frac{1}{2\pi fC}$.

In this formula, any increase of f or of C will increase the denominator of the fraction, and any such increase will reduce the

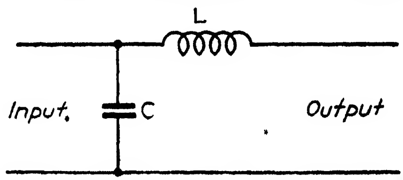


Fig. 180.—Circuit diagram of a simple low-pass filter.

value of the fraction or of X_c. The fundamental fact to remember is that, as the frequency is increased, the inductive reactance in a circuit increases and the capacitive reactance decreases. For example, in the circuit shown in Fig. 180, as the frequency of the input is raised, an increasing amount of the input will pass through the condenser, and the output will be diminished at the same rate. To bring out the same idea in a little different manner, suppose two signals of equal intensity but of different frequencies, one high and one low, are fed into the circuit. The high frequency finds a high impedance at L and a relatively low impedance at C; therefore, most of the high frequency will pass through C. The low frequency will find a high impedance at C and a relatively low impedance at L. The output, then, will contain a high percentage of the l-f input and a low percentage of the h-f input.

If we wish to have a high percentage of the higher frequencies and a low percentage of the lower frequencies in the output, the result is obtained by interchanging L and C in the circuit.

The most widely used tone control consists of a condenser in series with a variable resistance, with the combination across

the a-f circuit. This control simply attenuates the high frequencies and, thereby, makes the low frequencies seem stronger. Because of the reactance characteristics of the condenser, only the high frequencies are attenuated and the amount of this attenuation is governed by the setting of the variable resistor.

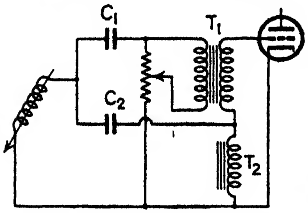


FIG. 181.—Circuit diagram of a compensating circuit to improve the h-f and l-f response of a phonograph pickup.

Tuned circuits are often used to increase the gain at the high or low frequencies. Usually a condenser of the proper value is connected across the primary of an audio transformer for the purpose of tuning it to 70 or 100 cycles. This arrangement will cause the voltage across the primary to be much greater at this frequency (just as tuning an r-f circuit does), thereby giving a marked increase in the amplification of the frequencies near the 70- or 100-cycle value. The effect can be controlled by putting a variable resistance in series with the condenser. The circuit should not be tuned to 60 cycles, for that would accent any 60-cycle hum.

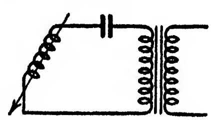


FIG. 182.—Circuit designed to increase the l-f response of a phonograph pickup.

Figure 181 shows the application of this system to a phonograph pickup for the purpose of extending both the h-f and l-f range.

The circuit containing the pickup, C_2 and T_2, is tuned to some high frequency, usually between 5,000 and 7,000 cycles. The circuit containing the pickup, C_1, T_1, and the variable resistance should be tuned to around 50 to 70 cycles. The variable resistance allows the proportion of low frequency in the output to be varied.

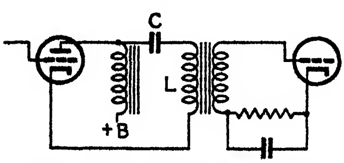


FIG. 183.—Circuit designed to increase the l-f response of an amplifier.

If the problem is simply to improve the l-f response, a much simpler solution is shown in Fig. 182. It tunes the primary circuit to some low frequency, usually approximately 50 cycles.

If this method does not bring out the low frequencies sufficiently, the scheme shown in Fig. 183 can be added. This scheme consists of using a parallel feed for the plate of the tube

and choosing the condenser C so that the circuit CL will be tuned to 70 cycles. Since this condenser is in a series-tuned circuit, the voltage developed across it at resonance may be many times the applied voltage. It is therefore necessary to use a condenser that has a high voltage rating, or a breakdown is very likely to occur.

Low-frequency compensation can also be maintained by using a series circuit, tuned to some low frequency, in place of the C bias by-pass condenser. If the amplification is to be confined to a narrow band of frequencies, use a large inductance and a small condenser to tune to the desired frequency. If, however, it is desired to spread the amplification over as wide a band as possible, then a small inductance and a large condenser should be used.

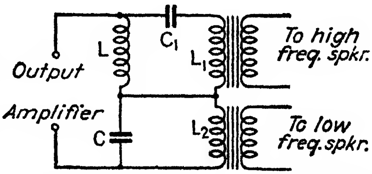


FIG. 184.—Circuit used in receivers having h-f and l-f speakers.

The same principles are used in designing output circuits for dual speakers. Figure 184 shows one circuit that can be used for this purpose. The higher frequencies meet a high impedance in the choke L and, therefore, follow the lower impedance circuit C_1 L_1, which is tuned to one of the higher frequencies. The lower frequencies are kept out of this path by the high

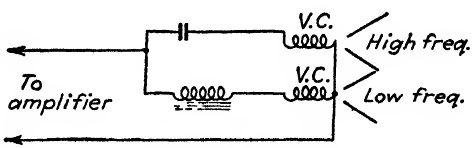


FIG. 185.—A simple circuit used in receivers having h-f and l-f speakers.

impedance to them of the condenser C_1. The low frequencies pass through L and are forced through L_2 by the high impedance of C. The very simple circuit shown in Fig. 185 is used in some sets and is also used in some of the sound systems in theaters.

A variation of this circuit is used in the Stromberg-Carlson 70 series high-fidelity receivers. This circuit is shown in Fig. 186.

A very excellent tone-compensating circuit is shown in Fig. 187. In this circuit, the relative amplification of the high and low frequencies can be regulated independently of each other. The

circuit $L_1 C_1$ is tuned to a suitable high frequency such as 6,000 or 7,000 cycles. The resistor across it may be 50,000 ohms. When the resistance is all cut out, the tuned circuit is short-circuited and has no effect. When the potentiometer across the condenser is all cut in, the tuned circuit raises the impedance of the plate load at the frequency to which it is tuned and, therefore, raises the amplification of that frequency. The circuit $L_2 C_2$ is tuned

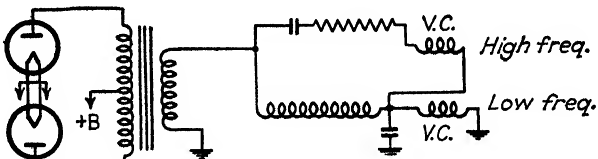


FIG. 186.—Frequency filter used in the Stromberg-Carlson 70 series receivers.

to some suitable low frequency, usually below 100 cycles, and works in the same manner as the h-f circuit. The resistance R governs the middle-frequency response. The chokes used in this circuit should be shielded or they will pick up 60-cycle hum voltages.

The introduction of inverse feed-back circuits has provided engineers with an entirely different method of controlling the

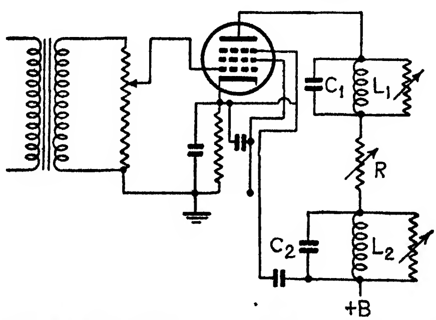


FIG. 187.—Circuit diagram illustrating the use of tuned circuits to adjust the h-f and l-f response of an amplifier.

tone characteristics of an amplifier. In Figs. 105 to 107 the voltage across R_1 is applied to the grid of the tubes. If it is desired to accent the higher frequencies, this resistor would be by-passed by a condenser. Since a condenser presents less impedance at higher frequencies, very little h-f feedback will be created and these frequencies will not be reduced.

If it is desired to boost the low frequencies, a choke would be substituted for the resistor R_1. In this case the impedance is low at low frequencies and, therefore, little l-f feedback will be developed.

This system gives a very satisfactory method of adjusting the tone characteristics of an amplifier permanently located.

Automatic Tone Compensation.—Several circuits that work in connection with the a.v.c. circuit have been developed for automatic-tone compensation. Figure 188 gives a schematic diagram of one of these circuits. When the signal is strong, the a.v.c. voltage will be high and the plate impedance of V_1 will be high (indicated by low I_p), owing to the high grid bias. Under these conditions, the high frequencies are kept from passing through the condenser C, for the impedance of the choke is also very high. However, when the signal is weak, the a.v.c. voltage will be low, and with low grid bias, the plate impedance of the tube will be low (indicated by high I_p), and so the higher frequencies pass through the condenser and the plate impedance of the tube. It will be seen that the plate impedance of the tube replaces the variable resistance of the usual tone control.

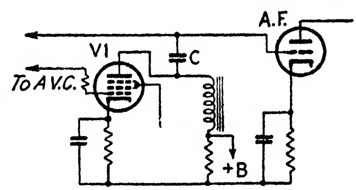


Fig. 188.—Circuit diagram of an a.t.c. circuit.

Automatic Frequency Control.—The phrase "automatic frequency control" is abbreviated a.f.c. Even before the advent of high fidelity, it was evident that there was a need of some device that would assist an operator of a radio set in tuning in a program accurately and thereby assure him of the maximum quality obtainable from the set. The problem became particularly acute when high-fidelity reception was attempted; for all the care and engineering skill that could be incorporated would not ensure high fidelity in a set unless it was accurately tuned to the broadcast station.

Automatic-frequency-control Circuits.—Automatic-frequency-control circuits solve many of the problems that have faced the radio engineer in his attempt to provide a maximum of quality for the listener. Foremost among these problems is that of accurate tuning. It is well known that many owners of receivers either will not, or cannot, tune the receiver exactly on the

station and therefore do not get the maximum quality for the receiver. But even if the receiver is accurately tuned to the station at the start, it will not remain so because of the shifting of the oscillator frequency. The shift in the oscillator frequency may be due to fluctuations in the line voltage or to changes in temperature or humidity. Most of the selectivity and amplification in a superheterodyne receiver is obtained in the i-f amplifier, and because of this fact it is essential that the signal fed into the i-f amplifier be of the proper frequency. The intermediate frequency is always the difference between the incoming r-f signal and the oscillator frequency and, therefore, depends on the oscillator tuning. All the a.f.c. circuits operate by controlling the oscillator frequency.

The frequency at which an oscillator is operating depends on the inductance and capacity in its tuned circuit and can be determined from the formula $f = \frac{1}{2\pi\sqrt{LC}}$. An inspection of the formula will show that any change in either the inductance L or the capacity C will change the frequency. In most radio circuits, the tuning is accomplished by changing the capacity, for this involves the fewest mechanical difficulties; however, a change of inductance is used in a.f.c. circuits. In effect, an inductance is put in parallel with the tuning inductance of the oscillator. Actually, the plate circuit of a vacuum tube is placed across the oscillator coil, and then the tube is made to behave like an inductance.

The following, rather detailed explanation should be carefully studied for two reasons in addition to its application to frequency-control circuits: (1) It shows how a tube can be made to behave like an inductance or a condenser. There are many applications of radio tubes outside of the field of communications which use these ideas. (2) Much of this circuit is used, without change, in frequency-modulated receivers.

Before the explanation of the operation of the tube is undertaken, it will be well to review the characteristics of an inductance. It will be recalled that an inductance opposes any change in the current flowing through it and that this action causes alternating current to lag behind the voltage when passing through an inductance.[1] A tube, then, will act like an inductance

[1] See p. 30, Chap. II.

if its plate voltage is alternating and the plate current can be made to lag behind the plate voltage. This can be done conveniently by operating on the grid voltage rather than on the plate current directly. Why this can be done is illustrated in Fig. 189.

In this figure, the signal voltage is positive during the portion of the cycle indicated by *ABC*. This must be so because it is canceling out part of the *C* bias and that is negative. The signal must be positive; otherwise it would add to the bias and not buck it. During this half cycle of the grid voltage, the plate current is changing from *A′* to *B′* to *C′*, which is also the positive

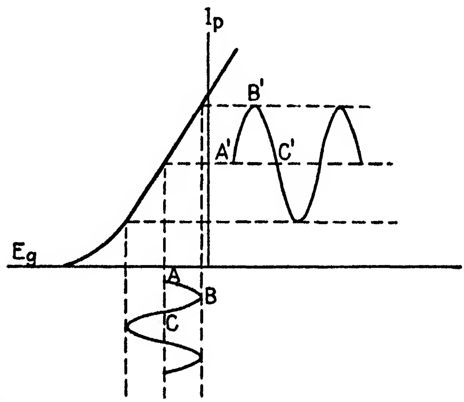


FIG. 189.—Diagram illustrating the phase relations between the grid voltage and the plate current of a vacuum tube.

half of the plate-current cycle. These facts show that the grid voltage and the plate current of a tube are always in phase. The tube will then act as an inductance if the grid voltage can be made to lag behind the plate voltage. The method of accomplishing this difference in phase relation is shown in the diagram in Fig. 190. The plate of the control tube is connected to the hot side of the oscillator inductance, which supplies it with an alternating plate voltage. The grid voltage of the control tube is obtained from the voltage divider composed of the two condensers C and C_1 and the resistor R. The condenser C_1 is used to block the d-c plate voltage from the grid. This condenser is so large that its impedance is very low and it has very little effect on the phase relations in the circuit. The impedance of

the condenser C is also very small in comparison with the value of the resistor R, and because of that fact the phase of the current flowing in the circuit will be dictated by the resistance. In a circuit containing little other than resistance, the current will be practically in phase with the voltage causing the current.[1] In this case, the current in the voltage divider circuit will be in phase with the plate voltage. But the current through the condenser C must be 90 deg. ahead of the voltage across the condenser; in other words, the voltage across the condenser must lag the current by 90 deg. But the voltage across the condenser is also across the grid-cathode circuit of the tube and

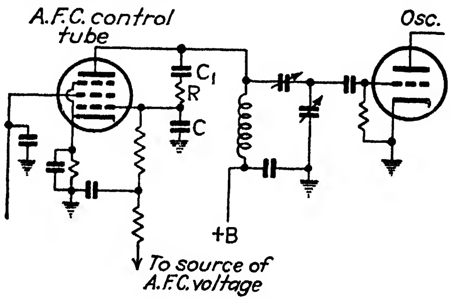


FIG. 190.—Circuit diagram of an a.f.c. control tube.

so is the grid voltage. The grid voltage, therefore, lags 90 deg. behind the plate voltage. Under these conditions, then, the tube will act as an inductance. Now the problem is to devise some method of changing the value of the inductance so that the frequency of the oscillator can be controlled. Again we must review the characteristics of an inductance. With a fixed voltage impressed on an inductance, the current will increase as the inductance decreases and will decrease as the inductance increases. The control tube then can be made to behave like a variable inductance by varying its plate current, which can be easily done by the proper adjustments of the C bias. A grid bias is obtained for the control tube by the usual cathode resistor. This bias voltage is combined with another voltage which is positive when the oscillator is tuned to a frequency higher than normal and negative when the oscillator is tuned too low. This additional voltage is obtained by means of the circuit shown in Fig. 191.

[1] See p. 31, Chap. II.

A complete and accurate description of the operation of this device will be found in connection with frequency-modulated radios. However, the action of the device can be understood without these details to a sufficient degree so that it can be intelligently serviced. This circuit is called the "discriminator" because it can discriminate, or tell, whether or not the intermediate frequency is too high, too low, or correct and act accordingly. The connections are such that, when the signal is accurately tuned in, the voltages across the two resistors R_1 and R_2 will be equal. The polarity of these voltages will be the same as for any diode circuit—the cathode end of the load resistor will always be positive. This brings the two voltages into opposi-

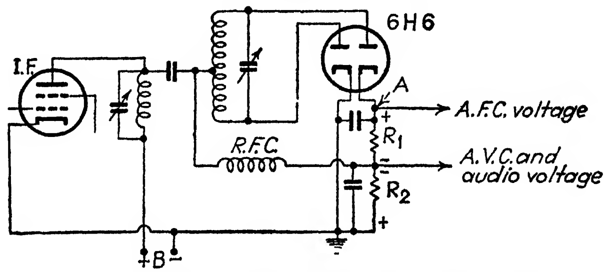


FIG. 191.—Circuit diagram of an a.f.c. discriminator.

tion. When they are equal, the point A is at ground potential; in other words, there is no a.f.c. voltage. However, if the station is not accurately tuned in, the two voltages across the resistors R_1 and R_2 will no longer be equal. If the set is tuned to a frequency above the resonant frequency, one resistor will have the higher voltage; and if the frequency is below the resonant frequency, the other resistor will have the higher voltage. These characteristics result in the point A being positive when the frequency is too high and negative when the frequency is too low. This voltage is then applied to the grid of the control tube whose circuit is shown in Fig. 190.

The a.f.c. circuit has other advantages besides the prevention of poor quality due to mistuning by the operator. It is just as effective in preventing distortion and fading on the higher frequencies due to oscillator drift.

Variations of the Automatic-frequency-control Circuits in Other Sets.—There are several other ways to obtain the proper phase relation between the grid and the plate voltages of the

control tube. In the Westinghouse model WR-315 receiver, a 75-ohm resistor is placed in series with the oscillator tuning inductance, and the voltage developed across this resistor is applied to the grid of the control tube. In this voltage-divider circuit, the inductance is the predominant impedance, and, therefore, the current will lag behind the voltage. However, the voltage across the resistor will be in phase with the current through it. The grid voltage, in consequence, will lag the plate voltage by the required amount.

In the Grunow model 12-B receiver, the voltage divider is across the plate feed-back coil of the oscillator rather than across the tuned circuit. This takes the load off of the tuned circuit and tends to prevent a stoppage of oscillation. An oscillator acts like any other machine in that excessive load will cause it to stop or act irregularly.

In a number of receivers, the a-f and a.v.c. voltages are obtained across a part, or all, of the load resistor of one of the discriminator diodes. When this method of obtaining these voltages is used, a resistance-capacity filter is used in the return lead to the center tap of the i-f transformer secondary to keep the i-f voltages out of the a.v.c. and a-f circuits. Another modification of the discriminator circuit is also required to obtain a minimum bias for the controlled tubes in the a.v.c. circuits. The lower end of the diode resistor is not grounded but connected to a point 3 volts negative in respect to ground and then by-passed to ground by a 10-mf. condenser.

Some of the a.f.c. lines are by-passed to ground by a condenser sufficiently large to make the time constant of the a.f.c. circuits greater than that of the a.v.c. circuits.

REVIEW QUESTIONS

9-1. Why are variable-mu tubes used when the volume is controlled by varying the *C* bias?

9-2. Show a diagram of a shunt-type audio volume control.

9-3. Show a diagram of an acoustically compensated volume control.

9-4. Why are volume controls acoustically compensated?

9-5. Name two advantages gained by using a.v.c. circuits.

9-6. Show the diagram of an a.v.c. circuit showing at least two controlled tubes.

9-7. What is a time-delay circuit? What is the principle of its operation?

9-8. Show a circuit diagram of a shorting-type rectifier.

9-9. Why are noise-suppression circuits used in connection with a.v.c. circuits?

9-10. Show a circuit diagram of a noise-suppression circuit.

9-11. Name three possible defects in a.v.c. circuits and explain possible causes.

9-12. Why are tone controls used?

9-13. Show a diagram of a simple low-pass filter.

9-14. Show a diagram of a simple high-pass filter.

9-15. Show a diagram for increasing the l-f output of a magnetic phonograph pickup.

9-16. Show a circuit for splitting the output of an amplifier between h-f and l-f.

9-17. What are the advantages of a.f.c. circuits?

9-18. What is the phase relation between e_g and i_p?

9-19. (*a*) What is the phase relation between the current through and the voltage across a condenser? (*b*) A choke coil?

9-20. Show a diagram of the oscillator control circuit of an a.f.c. circuit.

9-21. Show a diagram of the discriminator used with a.f.c. circuits.

CHAPTER X

LOUD-SPEAKERS

There are three main types of loud-speakers: magnetic, dynamic, and crystal.

Magnetic Speaker Motor.—The driving unit of this type of loud-speaker is usually of the balanced-armature type shown in

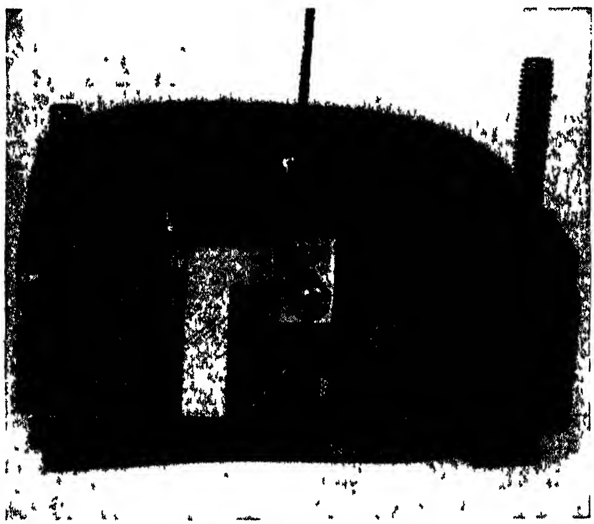


Fig. 192.—A magnetic speaker motor. One-half of each of the pole pieces can be seen above and below the end of the armature. The circular voice-current coil can be dimly seen surrounding the armature.

Fig. 193. It operates as follows: The driving-rod support, which is rather a stiff spring, holds the armature midway between the pole pieces. The alternating current from the amplifier flowing in the coil magnetizes the armature. During one half cycle, the top of the armature will be a north pole which will be attracted by the south pole and repelled by the north pole at the top of the pole pieces. At the same time, the bottom of the armature is a south pole. The attraction and repulsion at this end are in such a direction that they tend to rotate the armature

in the same direction as the upper section. During this half cycle, the upper half of the armature is forced to the left and the lower portion is urged to the right. When the current in

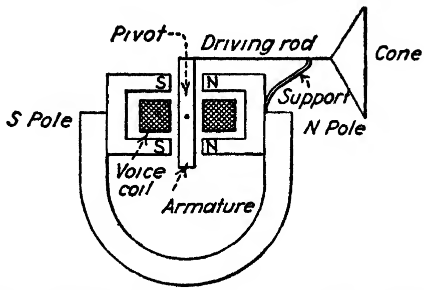


FIG. 193.—Diagram showing the construction and operation of a magnetic speaker.

the coil reverses, it reverses the magnetization of the armature and forces it in a direction opposite from the original one. The amount of the movement depends on the strength of the current

FIG. 194.—A dynamic speaker.

magnetizing the armature. This movement is carried to the cone by the driving rod. If the d-c plate current is allowed to flow in the voice coil, it will create a magnetic flux in the armature,

which will pull it off center. Under these conditions, the volume causing the armature to strike the poles will be much less than it would be if no direct-current were passing through the speaker. This difficulty can be largely overcome by adjusting the armature off center with no current in the coil. If the coil is then properly connected in the plate circuit, the direct current will tend to pull it back in the center.

The area of the cone is large, and for this reason it has a large frequency range; *i.e.*, it can handle high and low notes. The larger the cone, the lower the notes it can reproduce, provided that the driving unit is powerful enough to drive it.

Dynamic-type Speaker Motor.—The main drawback to the magnetic speaker motor lies in the fact that the armature has a limited range of movement. This limited range is due to the fact that, if the pole pieces are separated, the magnetic field weakens very rapidly, and a weak field would seriously lower the output volume.

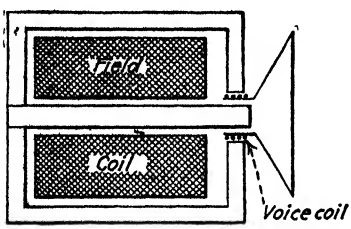


FIG. 195.—Diagram showing the construction and operation of a dynamic speaker.

The dynamic speaker is free from this difficulty. A cross section of this speaker is shown in Fig. 195. The field coil creates a strong magnetic field in the air gap occupied by the voice coil. The flux caused by the voice current reacts with this strong field and causes the voice coil to move in and out, carrying the cone with it. Owing to the construction of this speaker, the range of movement is much greater than in any of the others, and, for this reason, it reproduces the low notes with greater fidelity. On low notes of considerable volume, the movement may be as much as ¼ in. For low frequencies with this speaker, the cone does not vibrate but acts more like a plunger; however, for the higher frequencies, only the central portion vibrates. Many cones are ribbed because of this fact.

Hum-bucking Coil.—When the field supply current is not filtered, the pulsations in it will cause a hum in the speaker. To overcome or reduce this hum, a small coil is wound around the core and put in series with the voice coil. This is known as a "hum-bucking coil." It must be connected to the voice coil

so that the current induced in it by the pulsations opposes the current induced in the voice coil. If the connections of this coil are reversed, a very bad hum will result. Some speakers use a heavy copper disk placed around the core just behind the voice coil for hum suppression. This acts as a very low resistance short-circuited secondary and effectively prevents any hum from being induced in the voice coil.

Figure 196 shows several methods of exciting the field coil. One method is to wind it with large low-resistance wire and connect it to a 6-volt storage battery. A second method is to use

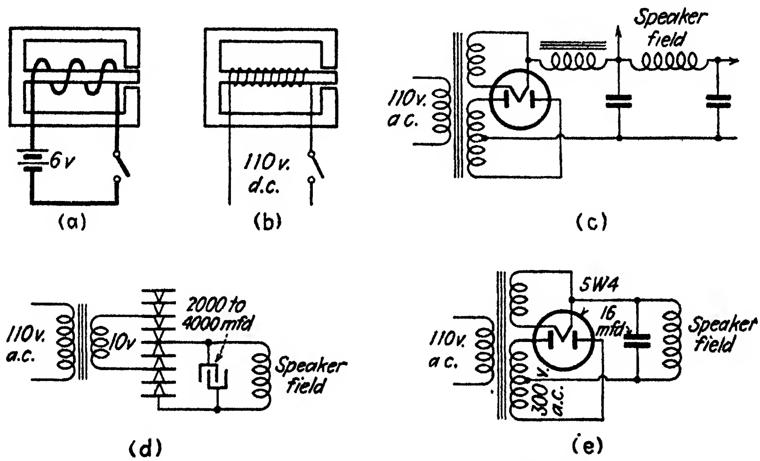


FIG. 196.—Methods of exciting speaker fields.

finer wire and connect it directly to 110 volts direct current. A third method is to wind it like a *B* power filter choke and use it in place of the second filter choke in the filter system. A fourth method, used where 110 volts alternating current is available, reduces this voltage to approximately 10 volts by a transformer and then rectifies it by any one of the dry-disk rectifiers. The output of the rectifier is filtered by a large (2,000-mf.) condenser connected across the field coil. In another method, a transformer steps up the voltage, which is rectified by a vacuum tube and then applied to a high-resistance field coil.

Recently two materials, Nipermag and Alnico, have been developed that are used as permanent magnet fields for dynamic speakers. These materials can be used to provide the same field

flux as the electromagnet coils and occupy even less space. The advantages of removing the necessity for supplying field-excitation current are numerous. It permits the use of dynamic speakers in public-address systems used in schools, hotels, etc., without extra wiring to provide field supply. It simplifies the addition of an extra dynamic speaker to a radio set. It reduces the size, weight, and complications in the wiring of portable public-address systems.

Dynamic speakers are manufactured both with and without an input transformer mounted on them. If no transformer is mounted on the speaker, then one having a low-impedance secondary especially designed for this type of speaker must be used in the set. A transformer is necessary to adapt the tube impedance, which ranges from 2,000 to 15,000 ohms, to the impedance of the voice coil, which is usually 15 ohms or less.

The dynamic speaker motors are capable of reproducing lower notes than the magnetic speaker motors. In fact, some of them accent the bass so much that they sound "drummy" or like "someone talking in a barrel."

The dynamic speaker must be used with a baffle board or be placed in a cabinet. The speaker chassis alone will give inferior quality.

Crystal-type Speaker Motor.—Several crystals, notably quartz and Rochelle salt, will expand and contract if they are subject to an alternating voltage. This action is utilized in crystal speakers, which require a large crystal of Rochelle salt. The driving unit consists of a square block made by cementing two pieces cut from the crystal on either side of a piece of tin foil, and then covering the sides with foil. The over-all dimensions are $2\frac{1}{2}$ in. square by $\frac{1}{4}$ in. thick. Three corners of this block are securely mounted in rubber pads, and the fourth is connected to the cone by a lever with a multiplying movement. One electrical connection is made to the foil between the plates and the other to the outer foil on the sides.

This speaker has a negative (capacitive) impedance of 25,000 ohms at 1,000 cycles per second, which gives it characteristics very much like those of a 0.03-mf. condenser. It is almost entirely operated by voltage and so requires very little power. This feature and its freedom from field-current requirements are very convenient in multispeaker installations, such as schools

and hospitals. Since the h-f response of a crystal speaker is very good, it can be used to reinforce the h-f range of a dynamic speaker by connecting it across the primary of the output transformer. The power output of the two speakers will be increased, because of the effect of the negative impedance of the crystal. Care should be used in connecting a crystal speaker in parallel with another type to see that the proper phase relations exist. To express the same thought in less technical language, the speaker will operate better with the leads connected in a certain way than it will if the leads are reversed. The power output of these speakers declines as the temperature rises but will return to normal when the temperature is reduced unless a temperature of 130°F. is exceeded.

Baffles.—All speaker motors should be used with a baffle of some type if satisfactory operation, especially at low frequency, is obtained. The reason for this is easy to see. Consider the half cycle during which the cone is moving forward. The air immediately in front of it is compressed and this layer of compression should travel out into space if the sound is to be transmitted. However, if no baffle is used, the compressed air slips around the edge of the cone to relieve the area of rarefied air immediately behind the cone. Since the lower frequencies take more time for a half cycle, there is more time for this effect to take place and consequently it is most pronounced at low frequencies.

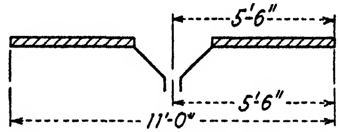


FIG. 197.—A speaker baffle.

The size of baffle required to reproduce any required l-f note can be obtained as in the following example. Suppose that the lowest frequency desired was 100 cycles per second. Since sound travels approximately 1,090 ft. per second, the wave length of a 100-cycle note would be $\frac{1,090}{100}$, or approximately 11 ft. The distance from the center of the cone in front to the center of the cone in the rear must be 11 ft. If a flat baffle is to be used, it would have to be 11 ft. square with the cone mounted at the center. This is shown in Fig. 197. If a box-type baffle with an open back such as a console-type radio cabinet is used, the distance from the front of the cone to the back of the cone would have to be the same as for a flat baffle. It is essential

that the baffle in either case be made of material that does not vibrate easily.

From the foregoing discussion it can easily be seen that it is very important to have a soundtight fit between the edge of the cone and the baffle, otherwise the whole purpose of the baffle would be lost.

Infinite Baffle.—Where it is essential to keep the size of the baffle comparatively small, the whole back of the cone may be enclosed in a soundtight box. In this case the box should have a thick lining of sound-absorbent material to prevent reflection of the sound waves from the inside of the box striking the cone and causing it to vibrate and thereby introducing distortion.

Methods of Adding Extra Speakers to a Set.—Figure 198 shows how a magnetic, or crystal, speaker can be connected to a

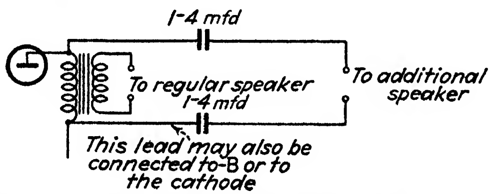


FIG. 198.—Method of connecting an extra speaker to a receiver having a single output tube.

radio set having a single power tube. The 1- to 4-mf. condensers should be connected close to the transformer so that the high voltage on the plate is confined to the radio chassis. If this were not done, there would be a potential of approximately 250 volts between the leads and the terminals of the new speaker and any ground, such as radiators, which might be touched accidentally. The condensers are also used to keep the plate current out of the speaker. The larger condensers give improved quality. The condenser forms a series-resonant circuit with the speaker winding, which, if tuned to 50 or 60 cycles, will increase the bass response of the additional speaker.

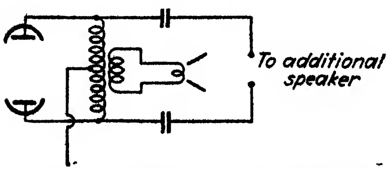


FIG. 199.—Method of connecting an extra speaker to a receiver having push-pull output tubes.

Figure 199 gives the circuit for connecting a magnetic or crystal speaker to a radio set having a push-pull output stage. The

extension cord may be soldered in place, but it is frequently easier to use wafer adapters that slip over the tube prongs and fit between the socket and the tube. The permanent-magnet dynamic speaker is especially easy to use as an extra speaker. It is impossible to connect an extra speaker without disturbing the impedance match of the original speaker and the set; however, satisfactory volume and the quality can be obtained. The voice coils of the original and the new speaker should be tried both in series and in parallel to determine which is more satisfactory (see Fig. 200).

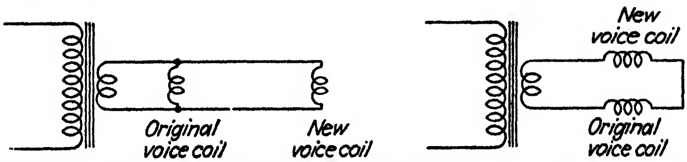


FIG. 200.—Circuits for adding an extra dynamic speaker to a radio set.

Trouble Shooting in Loud-speakers.—First, determine that the trouble is in the speaker by substituting for it, if possible, one that is known to be in good condition and then see if the trouble continues.

Be sure the cords are not worn. Tinsel cords may look all right but may be broken inside. A partly broken cord will cause a snapping or crackling sound, whereas a broken one will cause a speaker to be entirely silent, of course.

A metallic buzzing or rattling heard on certain notes is due to the vibration of some part. Look for loose screws and nuts. Tighten them. Put lock washers under all nuts. Inspect the cabinet for loose or cracked parts. If any are found, fasten them securely. Low output volume is often caused by a weak magnetic field due to loss of strength of permanent magnets or low exciting current in electromagnets. Permanent magnets may be remagnetized by slipping them through a coil carrying direct current and putting a keeper across the poles. If 115 volts direct current is available, the field coil from a small motor is suitable. If a storage battery is to be used, a coil should be wound of No. 16 d.c.c. (double cotton-covered) wire on a form 1¼ in. in diameter and ⅞ in. long. There should be 14 layers of 14 turns each. The outside diameter of the coil will be approximately 3 in. This coil will draw 12 amp. from the battery.

Tapping on the magnet while the current is passing through the coil will aid in forming a strong magnet. The current needs to be on for only a very short time.

Balanced-armature Type of Speaker Motor.—If the speaker is of the balanced-armature type, see if the armature is located midway between the pole pieces. Some speakers have one or more setscrews, which may be adjusted to center the armature. Many speakers have no adjustment for centering the armature. To center the armature in these speakers, unsolder the end of the connecting rod attached to the armature. Either end will do. Then wedge the armature in a central position by means of shims. Avoid the use of celluloid shims as they will burn very easily. Then resolder the connecting rod. Remove the shims, and test the position of the armature. It may have been pushed out of position by the weight of the soldering iron. If this is the case, it is necessary to try again. Try to have a drop of solder on the tip of the iron, and allow only this to come in contact with the armature. This will avoid misalignment. If there is direct current in the coils, offset the armature to counteract the effect of it as discussed earlier in this chapter.

Dents or tears in the cone will hinder its normal action. Minor tears can be repaired with cement. Avoid the use of patches. These stiffen portions of the cone and change its frequency response. If there is a joint in the cone, it will cause rattles if any portion of it is not securely cemented.

Grit and magnetic material should be removed from the armature gap. Cones, mounted in cabinets, should be adjusted to push firmly against the front of the cabinets. This will stop rattling sounds and will, in many cases, reproduce the lower frequencies better.

Dynamic Speaker.—Owing to the fact that the dynamic speaker usually handles more power and also because it reproduces the lower notes, special care should be taken to prevent every part of the chassis or cabinet from vibrating. Even the sides or panels in the cabinets may vibrate and ruin the tone of the speaker.

In some models, the moving coil is held in place by two or more flat springs. If these springs are out of adjustment, the coil will rub on the core or on other parts of the field structure. This rubbing will mar or entirely stop the reproduction if the friction is too great. To recenter a cone, the screw or screws holding

it in position should be loosened. The coil is then centered in the gap by means of paper, celluloid, or fiber shims and the screws tightened. After the shims are removed, the adjustment should be checked by moving the voice coil in and out with the fingers and listening and feeling for any rubbing.

Occasionally a voice coil will be found that has warped out of round to such an extent that it rubs. The only satisfactory repair of this condition is to replace the cone and voice coil.

Method of Installing New Cone and Voice Coil.—If the voice coil is attached to the cone when received, the first step is to locate the voice coil properly. It can be centered in the slot in the field by means of celluloid or paper shims. It should be pushed just deep enough into the slot so that the edge of the cone rests on the support to which it is to be fastened. The screws that fasten the voice-coil spider to the frame should now be tightened. The edge of the cone can then be cemented or otherwise fastened in place.

If the voice coil is not fastened to the cone when received, the voice coil should be mounted in place as before, then the cone placed in position, and the outer edge fastened. The last operation should always be fastening the cone to the voice coil. Be sure that the shims used to center the voice coil are pushed in the whole length of the coil; otherwise the back end of the coil may not be properly centered.

The felt ring around the edge of the speaker should be carefully replaced. If the joint between the speaker and its baffle is not practically airtight, the value of the baffle is largely lost and will result in the failure of the speaker to reproduce the lower notes.

The screws and bolts holding the field assembly together should be tight. Any looseness will cause a weakening of the magnetic-field flux and, as a consequence, a loss of volume and of tone quality.

Usually one side of the voice coil is grounded, and if the other side becomes intermittently grounded, owing possibly to the voice coil rubbing, much snapping and popping will result. If the proper ground is removed, howling may be caused due to the capacity between the primary and secondary of the output transformer.

To check the voice coil for continuity, one side should be disconnected from the output transformer. An ohmmeter reading

to less than 1 ohm should be used. Usually an open circuit occurs in the leads, which can in some cases be easily repaired.

An attempt to rewind a voice coil or make a cone is unprofitable unless a replacement cannot be obtained.

Phasing Multiple Speakers.—When more than one speaker is used in a cabinet, the voice coil and the field should be connected so that the voice coils of all the speakers move out and in at the same time. When one cone is moving outward as another is moving inward, the sound wave produced by one is absorbed by the other and little sound is produced by the combination. Reversing either the voice-coil or the field-coil leads of one of the speakers will cause them both to work together. The phasing of the cones can be checked by connecting a $1\frac{1}{2}$-volt dry cell in series with the common lead from the output transformer to the speakers. At the instant that contact is made, all the cones should move in or they all should move out. This can be determined by placing the fingers lightly on the cones as the contact is made to the battery.

Cabinets.—In some cases, a very disagreeable rattling or buzzing will be heard, which is caused by a loose panel or piece of veneer or possibly a crack in the paneling. The author has improved the audio response of several sets by repairing the cabinets. Loose panels can be secured by working glue in around the edges on the inside. Cracked panels can be kept from vibrating by gluing strips of wood on the inside over the cracks. The strips can be kept in place by loading them with heavy material until the glue is thoroughly set. Some of the cabinets with very thin panels can be improved by gluing a piece over the entire inside surface or as much of it as can be managed.

REVIEW QUESTIONS

10-1. Explain by a diagram the operation of a magnetic speaker motor.

10-2. What precaution should be used when the plate current of a tube flows through the windings in a magnetic speaker?

10-3. Explain by a diagram the operation of a dynamic speaker.

10-4. What advantages does a dynamic speaker have over the magnetic type?

10-5. Show the connections and explain the operation of a hum-bucking coil.

10-6. Indicate by diagrams or otherwise three methods of supplying the field flux for electrodynamic speakers.

10-7. Explain the operation of the crystal-type loud-speaker motor.

10-8. Explain why a baffle is necessary with a speaker motor.

10-9. What is an infinite baffle?

10-10. Show a diagram for connecting an additional high-impedance speaker to a radio.

10-11. Show a diagram for connecting an additional PM speaker to a radio.

10-12. Name three causes of trouble in speaker motors.

10-13. Describe a method of installing a cone in a dynamic speaker.

10-14. What is meant by "phasing" speakers?

10-15. Describe a method of phasing speakers.

CHAPTER XI

ANTENNAS AND THE ELIMINATION OF MAN-MADE STATIC

The magnetic and electrostatic lines of force that are sent out by the broadcasting station pass by the antenna conductors and induce a current in them in the same manner as it is generated in the secondary of an induction coil or in the coils of a generator. An antenna circuit is really a coil and a condenser in series, because the antenna and the ground together act as a condenser, and the antenna being a wire has some inductance. (See paragraph on "Inductance" in Chap. II.)

An antenna used exclusively for the 550- to 1,500-kc. band should be 75 to 100 ft. long, including the lead-in wire, and in a location free from electrical disturbance. Joints of any kind should be avoided. If any are necessary, they should be very carefully made and soldered. Since r-f current will be flowing in the circuit, the lead-in wire should have a large surface, because h-f currents travel only on the outside of the wire. For this reason, stranded wire is much superior to solid wire. The greater the number of strands in a given size of wire, the better it is for radio use. Each strand should be enameled to secure the best protection against corrosion.

Insulation is very important. Avoid the use of insulators that absorb moisture. Glass, particularly Pyrex, is one of the best insulating materials.

Keep the antenna as far away from the surrounding objects as possible. This precaution is especially true in the case of metal roofs, gutters, downspouts, metal cornices, etc. If power lines are near by, be sure to follow the Fire Underwriters' code regulations exactly. To avoid picking up the 60-cycle hum from power lines, stay as far away as possible and keep the antenna as nearly at right angles to the power lines as possible.

Number 14 r.c. (rubber-covered) wire is always used for a ground wire. A good ground is essential if satisfactory operation

is to be maintained. Many receivers will work at lower efficiency with a very poor or no ground, but a marked improvement will be shown with a good ground. Sometimes it is found that there is less noise picked up when the ground connection is not used. This effect is caused by the ground lead running through an area where the electrical disturbances are particularly severe. It should be remembered that the lead-in and the ground lead will pick up signals and noise as well as the aerial itself; in fact, the vertical lead-in and ground lead are even better collectors of noise than is a horizontal aerial. For this reason, it is often advisable to shield the ground lead, or to protect it against picking up noise, in the same manner that the lead-in is protected. Under these conditions, the performance of the radio is improved by the use of a ground lead. Most of the modern radio circuits are by-passed to the chassis. To make this system fully effective, a ground connection is required. Leaving the ground lead disconnected will have a tendency to increase the a-c hum, hand, or body-capacity effects, and circuit noise and feedback.

A rod or pipe driven down to moist earth is the best ground and should always be used if possible. Steam pipes are often used; but since they have rather high resistance, if the same steam pipe is used as a ground for two or more receivers, any disturbance picked up by any of the antennas will be reproduced by all the receivers. Gas pipe should never be used under any circumstances.

In making the connection to the ground pipe, care should be exercised to get a good clean connection. If paint, rust, or scale is left on the pipe, it is certain to cause staticlike noise sooner or later.

It has been discovered that man-made static is generated close to the ground and remains close to the ground except when it is carried upward by wiring or other metal structures. To eliminate man-made static, it is necessary not only to erect an aerial high enough to be above the zone of man-made static or far enough away from buildings and other sources of static to be out of the zone but also to protect the lead-in and ground wire from picking up the noise between the antenna and ground.

The first method commercially used to avoid man-made static was the shielded lead-in. This method necessitated a very large antenna, because the shield caused a large loss, due to the capac-

ity between it and the lead-in. It was not always completely effective. Much of this loss was avoided in later types of antenna by using properly constructed transformers at each end of the shielded lead-in.

Another type of lead-in, known as the "transposed lead-in," consists of a pair of twisted No. 14 r.c. wires that extend from the aerial to the ground. One wire is soldered to the antenna, and the second one is insulated at the antenna end. The second wire is connected to the ground, and the first wire is insulated at the ground end. The radio set is connected to both wires at any convenient point along their length.

Just how effective this last method is can be shown by the following experience:

A Western Electric superheterodyne used with a large public-address system had an inside aerial running along an attic almost completely enclosed with metal lath. At the h-f end of the broadcast band, the building noise picked up by the antenna was so great that it was impossible to hear a local station through it. An antenna 150 ft. long was placed about 20 ft. above the roof, and a transposed lead-in brought down to the set through the same route that the old antenna and lead-in had followed. With the old installation, the volume control had to be set above the middle position to receive even a local station at the l-f end of the band where the static was at a minimum. With the new installation, the signal was so large that every means available had to be used to prevent distortion due to overloading, and the building noise was eliminated entirely.

Transmission Lines.—Many of the commercial noise-reducing antennas have transformers installed at the antenna and at the set. The circuits of several of these are shown in Fig. 201.

The transformers are used to step down the impedance of the antenna to a low value so that interference will not be picked up by the transmission line. The voltage in this line is too low to feed into the input of the average radio set, and so usually a second transformer is used at the set to step the voltage up again. The circuit shown at (*a*) in Fig. 201 is balanced to ground; in other words, both sides of the circuit have the same capacity and voltage in relation to the ground, which is a help in avoiding interference. The static shields shown in the transformers in this circuit are used to prevent capacity coupling between the

circuits. The terminating resistances are used so that all frequencies will be transmitted with the same attenuation.

The transmission lines used for distances of 50 to 100 ft. are usually a twisted pair of wires. Ordinary lamp cord is not suitable because it is not weatherproof and therefore will have high losses. Many of the cheap varieties of transmission lines are not much better in this respect. For satisfactory results over a period of more than a few weeks a high-grade line should be used.

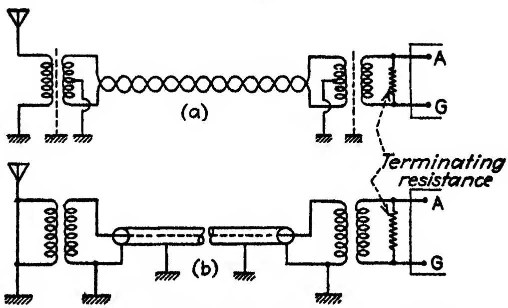


FIG. 201.—Noise-reducing antenna circuits.

When the length of the line exceeds 100 ft., the losses in a "twisted-pair" line become excessive and concentric cable should be used. This consists of a central conductor and an outer flexible tube. The two are insulated by Pyrex, or some other low-loss material, beads strung on the central conductor.

Sharp bends should be avoided in the installation of any transmission line.

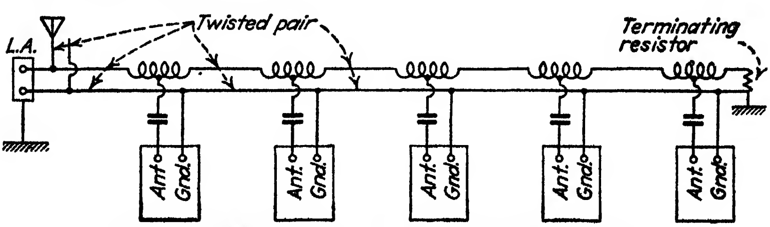


FIG. 202.—Multireceiver noise-reducing antenna circuit.

Antennas for More than One Receiver.—When more than one set are to be connected to the same antenna, the circuit shown in Fig. 202 may be used.

The various sets connected to this system will not interfere with each other unless one of the older type of superheterodyne

receiver, whose oscillator feeds energy into the antenna, or a regenerative set is used. There is no satisfactory method of preventing interference from these sets. The coils in this circuit have 46 turns of No. 24 wire wound on a 2-in. tube and center tapped. The condensers are 0.00025 mf. The terminating resistor is 750 ohms. Ten receivers have been used on this circuit with very good results.

It should be remembered that the use of any impedance-matching transformers or transmission lines always reduces the signal voltage at the receiver unless some additional means is used to boost it. With the preceding multireceiver installation, an antenna over 150 ft. long is used.

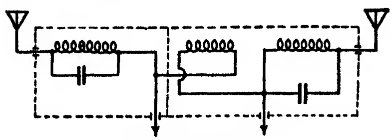


FIG. 203.—All-wave antenna circuit.

All-wave Antenna Systems. The all-wave sets present a problem in antenna design, because an antenna having a suitable length for the short waves is very inefficient for the broadcast wave lengths. One antenna system uses a short antenna designed for the short wave lengths. The high frequencies are fed through condensers to the set, and the lower frequencies are fed through transformers that raise the signal voltage, thereby compensating for the short antenna. The antenna-coupling transformer circuit is shown in Fig. 203.

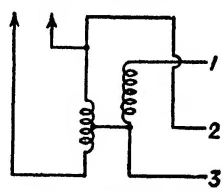


FIG. 204.—Circuit of a terminating transformer for the lead-in of an all-wave antenna.

The two tuned circuits must be resonant at some frequency other than those that are desired, because the resonant frequency will be blocked out of the receiver entirely. The circuit of the transformer used at the set with the antenna transformer already described is shown in Fig. 204. The terminals 1 and 3 are used for receivers with high-input impedance, whereas terminals 2 and 3 are used with receivers with low-input impedance.

There are many other schemes to use a single antenna for both long and short waves. It is important that any of these be installed according to the directions for the particular equipment. The length of the antenna is very important in all cases, and in some the length of the transmission line can be increased only by amounts that are halves of its original length.

The introduction of the frequency-modulated radios has presented another problem in antenna design. The type of antenna suitable for frequency-modulated receivers is so unlike that required by amplitude-modulated sets that two antennas are often used with sets designed to receive both types of transmission. Figure 205 shows a diagram of a single antenna that can be used for both types of transmission. The parallel-tuned circuit effectively isolates the long wire at the frequencies used by frequency-modulated stations but allows the whole length to be used at frequencies used by amplitude-modulated stations.

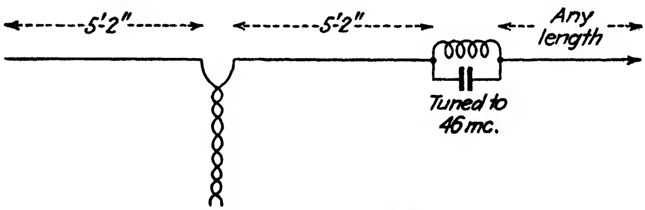


FIG. 205.—An all-wave antenna.

Noise-testing Receiver.—A great deal of time, work, and expense can be saved by the use of a noise-testing receiver to determine whether or not the location proposed for an antenna really is free from noise pickup. There have been many circuits proposed for such a receiver, some of them with several tubes and some of them employing superheterodyne circuits. But a very simple regenerative one-tube set having plug-in coils or some other way of covering several bands will be sufficient and will be much lighter to carry about and use on roof tops. It should be battery operated, and the whole set, batteries and all, should be completely shielded. The antenna may consist of two pieces of copper tubing, 2 to 5 ft. long, fastened at the end of an 8- or 10-ft. pole and connected as a doublet to a twisted-pair lead-in. The lead-in terminates at the set in a coil of about 10 turns coupled to the tuning inductance. The doublet antenna is directional. The source of the noise is in a direction at right angles to the antenna when it is turned so the noise is at a maximum. Headphones are used, of course.

By moving the portable antenna about in the space where the proposed antenna is to be erected and listening to the noise pickup, it can be very quickly determined whether or not the permanent installation will be successful in eliminating noise.

Noise-reducing Antennas.—Under modern conditions, any receiver should have a noise-reducing antenna; otherwise, the full sensitivity of the receiver can never be utilized without the presence of an annoying amount of interference. There are several types of noise-reducing antennas on the market. The fundamental principle of all of them is to erect the antenna in an area where there are no interfering signals and then conduct the desired signal from the antenna to the set by means of a transmission line that will not pick up any additional signals. The various makes of antennas differ widely in their design so that it is impossible to give any general instructions for all. There are instructions for installing with each kit and these should be followed. It will be found that the instructions for the various kits do not agree, but each is correct for its own installation. Many of the kits have tuned transmission lines. These transmission lines can be lengthened only by the addition of one or more quarter-wave lengths of wire. The original length is usually a half-wave length long.

Power-line Noise.—It will be found that the installation of a modern antenna does not always solve the problem com-

Fig 206.—A line filter with a circuit like Fig. 207.

pletely. Noise may also enter the set from the power-line connection, and it may be caused by conditions in the set itself. To check for these difficulties, disconnect the antenna and ground connection, and move them several feet away from the set. If the noise continues, try short-circuiting the antenna and ground connections with a very short piece of wire. If

the noise still is present, it must come from the power line or from something in the set. To test for noise coming through the power line, temporarily connect one of the better line filters in the power connection. If the noise is removed or is very much weaker, the trouble has been found. If the noise continues at nearly the same volume, it is evident that the trouble is inside the set. In this case, leaky condensers, faulty resistors, loose connections, grounded audio-transformer coils, poor socket contacts, etc., should be looked for.

In some locations, such as in the vicinity of power substations, large flashing signs, or diathermy equipment, it is impossible to eliminate all the noise without stopping it at its source.

Elimination of Man-made Static at Its Source.—Where it is impossible or impracticable to install a suitable antenna, disturbance can often be eliminated by stopping it at the source.

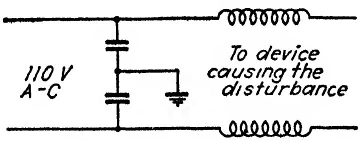


FIG. 207.—Circuit diagram of a line-noise filter.

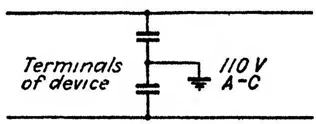


FIG. 208.—Circuit diagram of a simple line-noise filter.

Some of the causes of these disturbances are arc lights, vibrating rectifiers, mercury-arc rectifiers, dial telephones, magnetos, bad joints in streetcar rails, sparking trolleys on streetcars, poor connections in lighting circuits, and leaking insulators on high-voltage lines. The scheme shown in Fig. 207 can be used to eliminate some of the disturbances caused by this type of apparatus. This method has the advantage of stopping the annoyance for everybody and not for just one radio set.

There are several makes of line-noise eliminators on the market. They are all either condensers alone or condensers and chokes in circuits, as shown in Figs. 207 and 208.

Some of the so-called static in an a-c operated receiver comes to the set through the a-c line rather than through the antennas. This type of static is caused by any piece of equipment that sparks in any way. The brushes and commutators of small motors, such as those used on sewing machines, vacuum cleaners, mechanical refrigerators, mechanical stokers, and oil heaters, often become broken or rough and cause a constant stream of

fine sparks. These sparks act in a small way just as the old-fashioned spark transmitter did. Since they are not tuned to any frequency, they are heard all over the dial of a set. Another source of similar disturbance is found in the many automatic contact-making devices on the market. These are found in oil heaters, electric-heat controls of any type, electric refrigerators, electric bells, buzzers, automatically controlled flatirons, sign flashers, automatic electric traffic lights, etc. Electric heating pads contain many fine wires, which are easily broken. The current then jumps the tiny gaps thus made and is liable to cause noise in a receiver connected to the same line.

This type of noise can be eliminated, or reduced to such a degree that it is no longer bothersome, by the use of the proper line filter.

Antennas for Frequency-modulated Radios.—For satisfactory results, any short-wave radio, whether amplitude- or frequency-

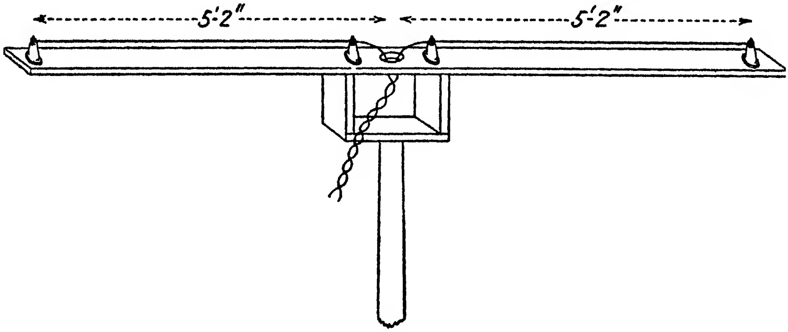


FIG. 209.—A dipole antenna.

modulated, should have an antenna designed to meet its needs. For frequency-modulated radios that operate in a band centering around 46 mc., a dipole antenna with a total length of a half wave length has been found most suitable. A diagram of this type of antenna is shown in Fig. 209. Each half of the antenna should be between 5 ft. and 5 ft. 4 in. long. This antenna has marked directional properties. Maximum reception will be received at right angles to the antenna. This fact can be used to cut out interference in cases where the interfering signal comes from a direction approximately 90 deg. from the direction of the desired signal. Where the reception of signals from trans-

mitters spaced at wide angles from the reception point is desired, some means of rotating the antenna must be provided, or an antenna having a total length of a full wave length (slightly over 10 ft.) or for still wider angle of reception a length of 1½ wave lengths should be used.

If reception is desired from a single direction, the use of a reflector behind the antenna will materially increase the signal strength. The reflector, a single rod or wire, should be approximately 5 per cent longer than the antenna. It should be parallel to the antenna and insulated in a manner similar to the antenna. The spacing between the reflector and the antenna should be adjusted for maximum results. It will probably be found between 3 ft. 2 in. and 5 ft. This reflector will block the reception of signals from its side of the antenna and can therefore be used to cut down interference from that direction.

Transmission Lines.—A twisted-pair transmission line is usually used. Because of the high frequency involved, it is essential that low-loss insulation be used and that the line be thoroughly weatherproofed. For long lines the use of coaxial cable is required to cut down the loss. The line used must match the antenna impedance at one end and the receiver input impedance at the other. In cases of mismatch, impedance-matching transformers should be used. If the transmission line is connected to the center of a half-wave antenna, its impedance should be approximately 70 ohms.

Antenna Installation.—High-frequency receiving antennas and transmission lines should be rigidly mounted because any swinging or other movement will alter the capacity to ground and a slight change in the capacity will result in a comparatively large change in the resonant frequency. As a rule, better reception will be obtained as the antenna is raised higher. However, it is often found that the signal strength will increase materially if the antenna is moved either *up* or *down* a few feet. It has also been noted that locations only a few feet apart horizontally have a marked difference in signal strength. For this reason it is an excellent idea to mount the antenna on its pole and then move it about on the roof to find the best location and height by listening to the signal strength for the various positions.

The regulations of the National Board of Fire Underwriters for antenna installations should be complied with in any event. It

is true that there are very few cities that inspect radio installations as they do electrical or plumbing installations. However, if an accident resulting in loss of life or property occurs, an investigation is always made and if it is revealed that the cause was an improperly installed antenna the installer will not be in a pleasant position. A copy of the regulations will be found in the Appendix.

A lightning arrester is required. For a single-wire lead-in the arrester is connected between it and ground. Two arresters—a double one—are required for a transmission line. One arrester is connected from each line to ground. This arrangement is also used with concentric cable unless the outer conductor is grounded, in which case no arrester is required for it.

Trouble Shooting on Antennas.—If disconnecting the antenna and ground leads from the set stops the trouble, it is safe to say it is either in the antenna or ground or has been picked up from some outside source. The antenna is such a simple piece of equipment that it would seem almost impossible for trouble to develop in it. This is often far from true. The following conditions may and do cause trouble:

Dirty or poor insulators cause leakage of the signal current and snapping and cracking in the loud-speaker. Always use glass or glazed-porcelain insulators.

Poorly soldered or unsoldered joints will have the same effect.

A dirty or defective lightning arrester may cause noise or stop reception entirely.

A loose swinging antenna will cause an effect like fading, owing to the changing of its tuning.

If the antenna or lead-in is close to any *grounded metallic substance,* such as tin roofs and gutters, weak signals can be expected.

Buildings with steel framework act as a shield and may block reception entirely in their direction.

Too long an antenna may add volume, but it broadens the tuning of a set so that the stations cannot be separated unless special precautions are taken.

The ground connection should be made to a separate ground rod if possible. The connection should be made with a pipe clamp. A loose or corroded connection at this point will cause noise or weak signals, or stop reception entirely. Sometimes the wire

may break inside the insulation and appear to be undamaged. This defect can be detected only by careful examination.

REVIEW QUESTIONS

11-1. What type of wire is suitable for antenna and lead-in?

11-2. What type of insulator is best for antennas?

11-3. What size of ground wire may be used?

11-4. How can 60-cycle hum pickup from power lines be avoided?

11-5. Which type of ground is best?

11-6. What should not be used as a ground?

11-7. Why is a shielded wire lead-in usually unsuccessful?

11-8. What is a "transposed" lead-in?

11-9. Why are grounded center taps used on transformers in connection with transmission lines?

11-10. Describe the construction of concentric-cable transmission lines.

11-11. Show by diagram or otherwise the construction of an antenna suitable for both AM and FM reception.

11-12. What is the purpose of a noise-testing receiver?

11-13. Describe a suitable receiver for noise testing.

11-14. What precaution is necessary when lengthening a tuned transmission line?

11-15. How can noise from power lines be kept from getting into a radio?

11-16. What test can be made to determine whether or not noise is coming in through a power line?

11-17. Name five sources of noise on power lines.

11-18. Show a diagram for a line filter.

11-19. From what direction will the best reception be received with a dipole antenna?

11-20. Under what circumstances is a reflector used with a dipole antenna?

11-21. State four provisions of the Fire Underwriters' Code for receiving antenna installations.

11-22. Show by diagram or otherwise the connections of a lightning arrester to a two-wire transmission line.

11-23. Name five common difficulties with antennas.

CHAPTER XII

SUPERHETERODYNES

Hetero, in Greek, means "other"; dyne means "power." Literally, superheterodyne means higher or greater power. The "other" power in a superheterodyne circuit comes from the oscillator. The ordinary power is, of course, the signal from the antenna. The oscillator is a miniature transmitter.

Briefly, the theory of superheterodynes is this: The incoming signal is received by the detector, which also receives the output of the oscillator. The output of the detector has in it the signal frequency, the oscillator frequency, and also the sum and the difference of these frequencies. Since the r-f signal is not a single frequency but a band of frequencies, the difference between all these frequencies and the oscillator frequency, which is a single frequency, will be another band of frequencies having the same width as the original band. This band of frequencies is fed into the intermediate amplifier, which is designed to amplify it to the best advantage. The second detector and the audio amplifier are the same as the detector and a-f amplifier in t.r.f. sets. The intermediate amplifier operates at a fixed frequency. The oscillator frequency is adjusted so that it is always operating with a *fixed frequency difference* between it and incoming signal. The methods of maintaining this fixed frequency difference will be discussed in Chap. XIV.

Figure 210 illustrates the formation of the intermediate frequency. In this figure, the oscillator output is illustrated by a solid line and the signal by a dotted line. In the time interval indicated, there will be found 6 cycles of the oscillator frequency and 4 of the signal frequency. As was mentioned before, these frequencies combine in many ways. The combination we are interested in is obtained by subtracting the signal frequency from the oscillator frequency. The dash line indicates this difference. This curve was obtained by subtracting algebraically the ordinates of the signal frequency from those of the oscillator

frequency. The result is a modulated wave as shown. If this wave is then fed into a detector, it will be demodulated as shown in Fig. 160. The output of the detector will then be a pulsating current having the shape of the envelope of the input signal. This is also shown in Fig. 160. We may consider the time interval *A-B* to be 1 sec. The oscillator frequency will then be 6 cycles per second and the signal frequency 4 cycles per second. The difference is 2 cycles per second, and this checks with the 2 cycles of the envelope shown in the diagram and with the theory given before.

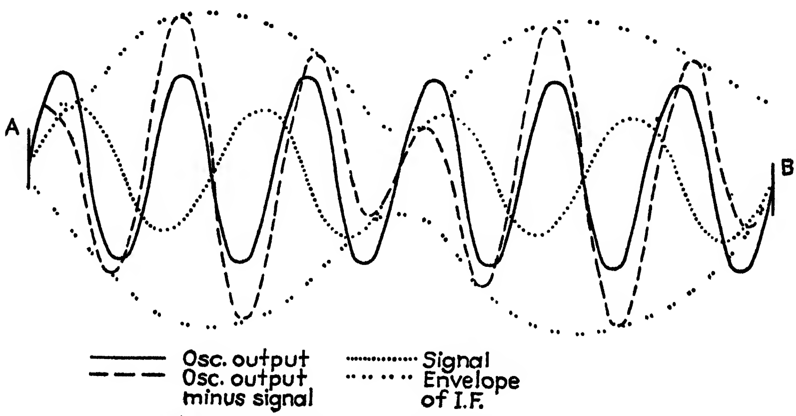


FIG. 210.—Diagram illustrating the formation of the intermediate frequency in a superheterodyne receiver.

The regenerative detector can be used to receive unmodulated code signals by using this same principle. The detector tube is made to oscillate at a frequency that is about 1,000 cycles above or below the incoming signal. Both signals are then applied to the grid of the tube, which acts as a detector. In this case, the difference frequency would be 1,000 cycles, which is audible. The plate by-pass condenser, which is always connected from the plate to the cathode of these detectors, is used to by-pass all the other unwanted combinations of the two frequencies. Fortunately these are all higher than the difference frequency and so can be filtered out by means of this condenser.

And now, returning to the discussion of the superheterodyne circuit, we recall that the output of the detector includes many other frequencies besides the one that has been considered in

detail. All these frequencies are fed into the i-f amplifier but, since it is tuned to the difference frequency, this frequency will be the only one that is amplified. In this respect, the i-f amplifier is like any t.r.f. amplifier.

So far, for the sake of simplicity only unmodulated waves have been discussed. It is not easy to show by means of a diagram, but it is nevertheless true, that if the incoming signal is modulated the i-f wave will have the same modulation. Because the intermediate amplifier operates at a fixed frequency, it is possible to obtain more gain, greater stability, and increased fidelity than is possible with an amplifier that must cover a wide frequency band. Intermediate frequencies from 25,000 to 3,000,000 have been used. For a number of years, 175 kc. was standard, until the introduction of the all-wave set made it necessary to change to some higher frequency. Frequencies in the vicinity of 460 kc. are common at the present time.

Intermediate Frequency.—The choice of the intermediate frequency is governed by several considerations. For the broadcast band, frequencies around 30 to 70 kc. give very high selectivity from adjacent channels, and very little difficulty with oscillation occurs in the intermediate amplifier. The disadvantage of the low intermediate frequencies lies in an interference known as "image-frequency interference."

Image-frequency Interference.—It has already been stated that the intermediate frequency is always the difference between the incoming-signal frequency and the oscillator frequency, which is usually higher than the incoming-signal frequency but not necessarily so. To illustrate just what causes image-frequency interference, suppose a signal of 1,000 kc. is being received and the intermediate frequency is 50 kc. The oscillator frequency then would be 1,050 kc., so that

$$1{,}050 - 1{,}000 = 50 \text{ kc.}$$

But a station on 1,100 kc. would give the same result,

$$1{,}100 - 1{,}050 = 50 \text{ kc.};$$

therefore, both of these stations, one transmitting on 1,000 kc. and the other on 1,100 kc., would be accepted by the intermediate amplifier and very bad interference would result. The expression "image frequency" is taken from a similar phenomenon with

mirrors. The image of an object that is in front of a mirror seems to be as far behind the mirror as the object actually is in front of the mirror. In a like manner, the signal causing image-frequency interference is always as many kilocycles away from the oscillator frequency on one side as the desired station is on the other side. To avoid this difficulty, the interfering station signal must be prevented from getting into the first detector. Many sets use one or two stages of r-f amplification ahead of the first detector for this purpose. Other sets use a band-pass circuit with a sharp cut-off giving good selectivity for the same purpose. By using an intermediate frequency above 475 kc., all image-frequency interference from other stations in the broadcast band can be eliminated. This is due to the fact that with these intermediate frequencies the frequencies that could cause interference are outside the broadcast band. For example: If the intermediate frequency is 480 kc. when the signal is 550 kc., the oscillator is set at 1,030 kc.

$$1{,}030 - 550 = 480 \text{ kc.}$$

The signal causing image-frequency interference would have to be 480 kc. above the oscillator frequency, or 1,510 kc., which is above the broadcast band. For signal frequencies above 550 kc., the frequency of the interference would be still higher.

Intermediate frequencies such as 175 and 462 are chosen so that the image frequency will not fall on an assigned broadcast frequency, thereby making the elimination of the interference easier. The use of the higher intermediate frequencies results in less image interference, but the adjacent channel selectivity is much poorer. This difficulty is also overcome by the use of highly selective circuits ahead of the first detector. In localities near high-powered long-wave stations, interference is experienced if the intermediate frequency used is near that of the station. For this reason the frequency of 456 kc. has been set aside for use as an intermediate frequency and no long-wave stations will be allowed to operate at frequencies close enough to cause interference. These interfering signals are picked up by any insufficiently shielded wiring or coils in the i-f amplifier. The oscillator or the r-f circuits ahead of the intermediate amplifier have no effect on this type of interference.

There are other methods of overcoming image-frequency interference, one of which is shown in Fig. 211. This scheme is used on some of the Sparton sets. The signal coming through the very small condenser C_s will be in the opposite phase from the signal coming through the band-pass circuit; and, when its volume is adjusted by varying C_s, these signals cancel each other. The desired signal is also reduced by the same amount, but, since this is a very small amount, the loss is more than compensated by the freedom from image-frequency interference.

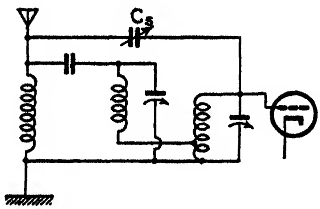


Fig. 211.—Circuit diagram of the anti-image-frequency interference circuit in a Sparton receiver.

A number of sets use the circuit shown in Fig. 212. The whole coil L_1, L_2, and the condenser C are tuned to the desired station. The portion of the coil L_1 and the condenser C are tuned to resonate at the most annoying interfering station. Unfortunately this circuit will not operate at any other frequencies so far as image suppression is concerned. Tuning over the band is perfectly normal, but image-frequency suppression occurs at only one position of the dial. Some of the Atwater-Kent sets had a circuit that eliminated image-frequency interference at all points on the dial. The circuit is shown in Fig. 213. C_1 is the main r-f tuning condenser. The condenser C_2 is a section of the gang condenser which tunes the circuit L_2C_2 so that it is always twice the intermediate frequency above the frequency to which the main tuning circuit is tuned. This is the frequency that would cause interference if the circuit L_2C_2 did not suppress it.

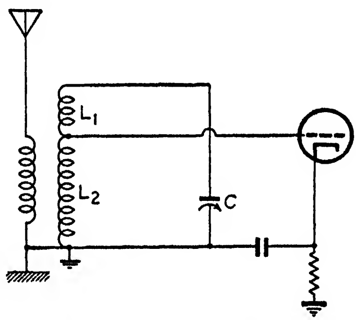


Fig. 212.—Circuit designed to eliminate image-frequency interference at a specified frequency.

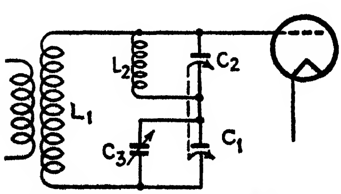


Fig. 213.—Circuit designed to eliminate image-frequency interference at any frequency.

Double Superheterodyne.—The advantages of both the high and low intermediate frequencies can be secured by using two intermediate frequencies. This circuit is known as a "double superheterodyne." The output of the first detector is fed into the first l-f amplifier. This is usually tuned to approximately 460 kc. An oscillator with fixed tuning feeds into the second detector, creating the second intermediate frequency, which is quite low. The third detector corresponds to the usual second detector in a normal superheterodyne circuit. The first intermediate frequency removes any image interference, while the second intermediate frequency provides interchannel selectivity. Thus the advantages of both high and low intermediate frequency are secured without the disadvantages of either. There have been a few double superheterodyne sets on the market.

Wave Traps.—In cases where a single station causes bad image-frequency distortion, a wave trap can be used in the antenna lead-in circuit. When the lead-in is a single wire, the circuit is shown in Fig. 214. The circuit L_1C_1 is tuned to the undesired station. The coil L_2 consists of two or three turns wrapped around the end of L_1. To be effective, the lead from L_2 to the set and the set must be thoroughly shielded. When a two-wire transmission line is used, the wave trap consists of a coil and condenser connected in series and tuned to the troublesome frequency. This circuit is connected across the transmission line.

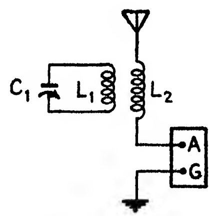


Fig. 214.—Circuit illustrating the use of a wave trap to eliminate image-frequency interference.

When it is desired to receive high frequencies, a high intermediate frequency is always used. It is very difficult, if not impossible, to prevent changes in temperature, line voltage, and load from causing the oscillator frequency to drift from its proper value. When this occurs, the intermediate frequency produced varies the same number of cycles. If the intermediate frequency is high, this drift will be a very small percentage of the number of cycles used as the intermediate frequency and will, therefore, be relatively unimportant. If the intermediate frequency is low, the same number of cycles drift would be a higher percentage of the total and would, therefore, cause more difficulty than the higher frequency.

FIG. 215.—A wave trap and its shield.

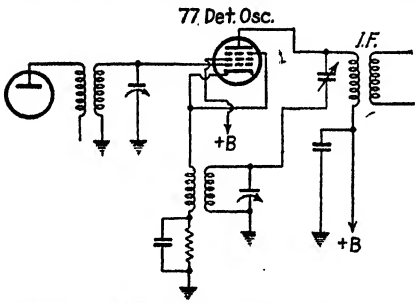


FIG. 216.—Circuit diagram illustrating the use of a sharp cut-off r-f pentode as a detector oscillator.

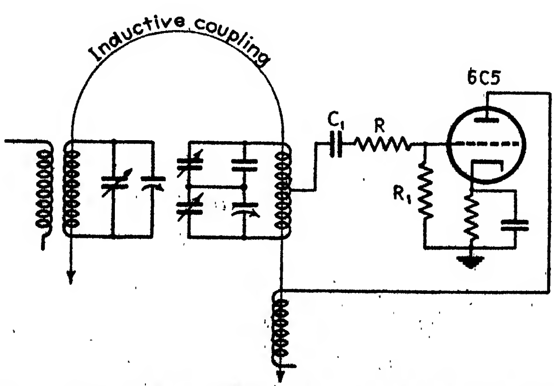


FIG. 217.—Circuit diagram of a separate tube used as an oscillator.

Since h-f oscillators are less stable than those of lower frequency, the oscillator frequency in h-f receivers is often below

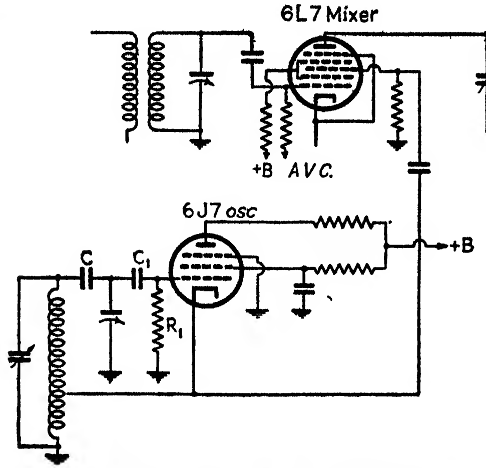


FIG. 218.—Circuit diagram of a 6L7 mixer tube.

the incoming-signal frequency. This is not so at broadcast frequencies, because of the difficulty of tuning the oscillator over the range of frequencies required.

Oscillators.—There are several circuits used for the oscillators in superheterodynes, four of which are shown in Figs. 216 to 219. The pickup coil can be placed in any of the circuits of the detector.

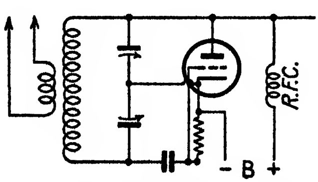


FIG. 219.—Circuit diagram of a Colpitts oscillator.

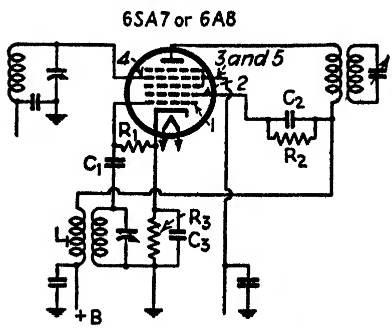


FIG. 220.—Circuit diagram of a 6A7 tube as an oscillator modulator or electron-coupled oscillator.

Figure 220 gives the schematic circuit of the 6A8 tube in which the functions of oscillator and first detector are combined in one tube. This tube is also called an "oscillator modulator"

or "electron-coupled oscillator and pentagrid converter." The 1A7GT, 6SA7, and 12SA7 tubes belong to this class. They have five grids surrounding the cathode. Grid 1 is used as the grid of the oscillator. Grid 2 is the plate of the oscillator. Grids 3 and 5 are internally connected and act as a screen grid. Grid 4 is the detector grid or the grid to which the r-f signal is impressed. A study of the diagram will show that the circuit of the oscillator is similar to the regenerative detector shown in Fig. 169. R_1 and C_1 are the grid leak and condenser. R_2 is a voltage-dropping resistor by-passed by C_2 for the radio frequency flowing in the plate coil L_1. R_3 is the C bias resistor by-passed by C_3.

The positive potential on the plate of this tube causes a stream of electrons, which pass through all the grids. Grids 1 and 2 have r-f voltages impressed on them because of their connection to the oscillator circuit. These voltages are alternating and so alternately attract and repel the electrons. As a result of this action, the stream of electrons is modulated, *i.e.*, becomes weaker and stronger at the frequency of the oscillator. The detector grid has the r-f signal voltage impressed on it, which also modulates the electron stream. The electron stream, then, is modulated by both the oscillator frequency and the signal frequency.

Grid Leak and Condenser.—The grid leak and condenser R_1C_1 in Figs. 217 and 218 are used to secure an automatic grid bias for the oscillator tubes.

With the grid connected to the cathode by the grid leak, the bias on the grid is, of course, zero when the tube is not oscillating. A tube so operated is very sensitive to any circuit change and is very unstable. With a positive voltage applied to the plate and the heater current turned on, the first surge of electrons from the cathode to the plate will cause the tube to start regenerating and within a few cycles this will build up sufficient feed-back voltage to cause the tube to oscillate. With the tube oscillating, the voltage feedback from the plate circuit will alternately make the grid positive, then negative. When the grid goes positive, it will act as a diode plate and attract some of the electrons that would otherwise go to the plate, and these electrons flowing through the grid leak will develop a voltage that will bias the grid negative. If the grid condenser and leak are of the proper value to prevent all of these electrons from leaving the grid during the negative cycle, the grid will

maintain this bias as long as the tube is oscillating. This effect can be shown in two ways: (1) by connecting a 0–1 milliammeter in series with the grid leak, and (2) by connecting a milliammeter in series with the plate-return circuit. When the tube is not oscillating, the plate current will be higher than when it is oscillating. The use of a meter in series with the grid leak gives a very good indication of the actual voltage developed by the oscillator. It is only necessary to multiply the grid-leak resistance in ohms by the grid current to determine this voltage. Since the voltage developed by an oscillator is proportional to the coupling, this grid-current measurement gives a good test for determining the condition of coupling. This current is larger than would be supposed, because, when the grid is positive, the plate voltage is at minimum and the grid attracts a relatively large percentage of the electrons. Since the translation gain of the first detector-oscillator combination is a function of the oscillator voltage, it is very important that this developed voltage be of satisfactory amplitude.

It is apparent from the foregoing discussion that an oscillator circuit that will cover the desired frequency band with a satisfactory developed oscillator voltage so as to give good translation gain and yet not cause parasitic oscillation trouble at the high-frequency end of the band, is one that has been very well engineered and one that must be intelligently adjusted in the field, if satisfactory receiver operation is to be maintained.[1]

Most oscillator circuits, unless compensated, give a higher output at the higher frequencies than at the lower ones. When the coupling between the oscillator and the detector is sufficient at low frequencies, parasitic oscillations (unwanted oscillations, usually at high frequencies) sometimes occur. There are two methods used to overcome this difficulty: one consists of a fixed condenser (*C* in Fig. 218) placed in series with the oscillator tuning condenser, and the other consists of a resistor (*R* in Fig. 217) placed in series with the oscillator grid. The 6SA7 type of oscillator modulator works very satisfactorily except at the ultrahigh frequencies. At these frequencies the impedance of the capacities between the signal and the oscillator grids is so low that the signal frequency can reach the oscillator grid. It therefore has a tendency to cause the oscillator to operate at its frequency, which, of course, prevents the formation of the i-f frequency. To avoid this difficulty a separate tube is used as an oscillator, as in Fig. 218.

[1] See *Sylvania News*, Vol. 6, No. 12, March–April, 1937.

Superheterodyne Circuit.—Figure 221 gives a block diagram of a superheterodyne showing the path of the signal through the circuit.

The circuit of the Philco model 37-620, a superheterodyne of the modern type, is shown in Fig. 222. This receiver covers two bands, 530 to 1,720 kc. in one range and 2.3 to 22 mc. in two ranges. There are three sets each of antenna coils, r-f coils, and oscillator coils. Switching of all the coils is done simultaneously by means of a three-gang switch. In the diagram, the three gangs are distinguished by the letters *A*, *B*, and *C*. The input-terminal board is arranged for either the old-style aerial and ground or a transmission line. For the

FIG. 221.—Block diagram of a superheterodyne.

antenna and ground connection, the link is placed between 2 and 3 on the terminal board. This grounds the upper end of all the antenna coils. When a transmission line is used, the link is placed between 3 and 4. This grounds the center of the antenna coils and gives a transmission line balanced to ground as discussed in Chap. XII. The oscillator circuits are similar to those shown in Fig. 220. The grid leak and grid condenser are 16 and 12, respectively. Condensers 4, 18, 18*a*, 18*b*, and 20 are used to align the various coils. The shadow meter measuring the plate current of the 6A8G tube can be used as a tuning indicator, for as the station is tuned in, the increased a.v.c. voltage will lower the plate current. Low current through the meter will cause a narrow shadow to be produced. The right diode plate is used for detection. Resistors 32 and 34 are the load resistors. The audio output is tapped off between the two resistors and fed through the condenser 47, which blocks the direct current. The volume control 48 is compensated for bass response by the resistor 45 and the condenser 43. Additional bass compensation is secured by the by-pass condensers 59 and 61 in the plate circuit of the output tube. Several degrees of bass compensation are obtained by the use of the switch 60. The left diode used as a shorting rectifier provides the a.v.c.

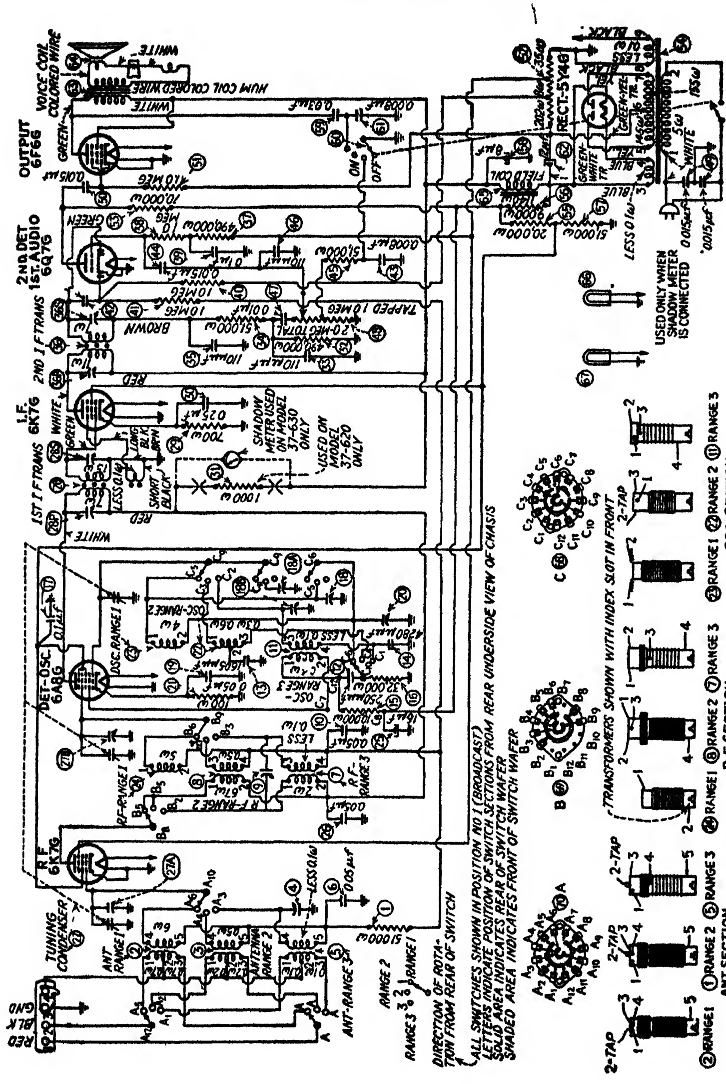


FIG. 222.—Circuit diagram of an all-wave superheterodyne. (*Courtesy of the Philco Radio and Television Corporation.*)

voltage that is applied to the first two tubes only. The resistor 52 places a negative bias on the a.v.c. diode and provides delayed a.v.c. This same voltage acts as a grid bias on the first two tubes, the second of which also has a self-biasing resistor 21 for additional bias. Since the field of the speaker is used as the only filter choke in the receiver, there must be considerable ripple voltage across it. This voltage would create an annoying

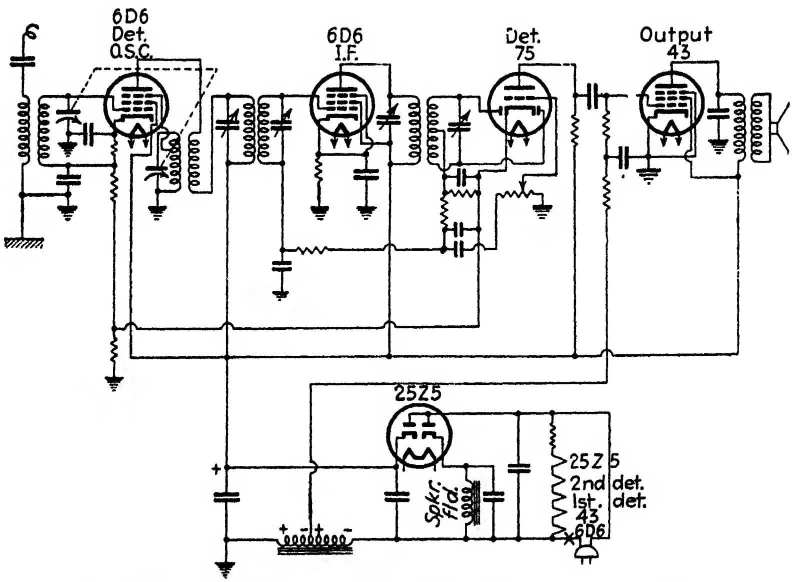


Fig. 223.—Circuit diagram of a midget superheterodyne receiver.

hum in the speaker if it were not neutralized by the hum-bucking coil in series with the voice coil.

The application of the superheterodyne principle to a midget receiver of the universal type is shown in Fig. 223. In this circuit, the suppressor grid and the plate of the first detector are used as the oscillator. The oscillator voltages appearing on the suppressor grid affect the electronic stream in much the same way that the voltages on the oscillator grids of the 2A7 operate. The other features of the set have been discussed in preceding chapters. The diode detector is full wave. The a.v.c. circuit controls the i-f tube only because a.v.c. cannot be used on this type of detector modulator. A portion of the

voltage drop across the filter choke is used to supply the grid bias for the type 43 output tube. One half of the 25Z5 rectifies current for the receiver, and the other half supplies the excitation for the field.

REVIEW QUESTIONS

12-1. How is the intermediate frequency formed?

12-2. What would be the oscillator frequency required to obtain a 465-kc. i-f from a 1,000-kc. signal?

12-3. A short-wave receiver is tuned to a signal frequency of 3 mc.; the oscillator is tuned to 4.5 mc. What is the intermediate frequency?

12-4. Why is an intermediate frequency used?

12-5. What are the advantages and disadvantages of a low intermediate frequency?

12-6. What are the advantages and disadvantages of a high intermediate frequency?

12-7. What is a double superheterodyne?

12-8. What is the advantage of a double superheterodyne?

12-9. What is meant by image-frequency interference?

12-10. At what frequency could a transmitter cause image-frequency interference if the desired signal was 760 kc. and the intermediate frequency 460 kc.?

12-11. Show a circuit of a wave trap for a two-wire transmission line.

12-12. Show a circuit of a mixer-oscillator circuit using a signal tube.

12-13. Show a circuit of a mixer oscillator using a 6L7 and a separate oscillator tube.

12-14. Why are high intermediate frequencies used in short-wave receivers?

12-15. Show a circuit diagram of a single r-f stage, a mixer oscillator, one i-f stage, and a diode detector providing a.v.c. for the i-f and r-f tubes.

CHAPTER XIII

FREQUENCY-MODULATED RECEIVERS

Modulation.—Before we can get into the subject of frequency-modulated (abbreviated FM) receivers, we shall have to get a clear idea of just what modulation is. Modulation is the process of varying a carrier, which in the case of radio is an r-f current, in some manner by the desired signal so that the carrier will bring the message to the receiver where it is demodulated or detected.

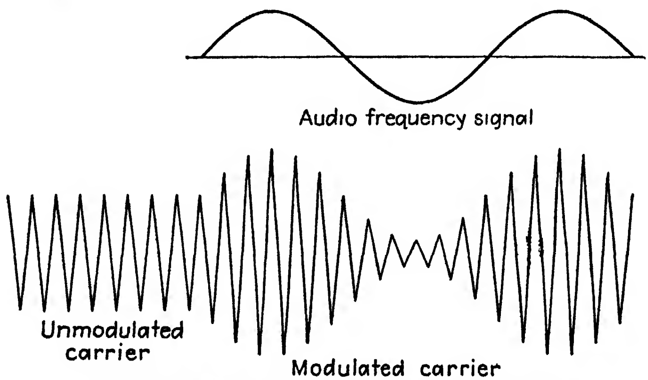


FIG. 224.—An amplitude-modulated radio wave.

There are several types of modulation. For a number of years amplitude modulation (abbreviated AM) has been used. By this method the amplitude or strength of the radio wave has been varied by the audio signal. This is illustrated in Fig. 224. Note particularly that in amplitude modulation the amplitude of the wave or the strength of the signal varies but the frequency remains constant.

When frequency modulation is used, the amplitude of the wave is constant but the frequency varies. When the a-f input is a low frequency, the frequency varies slowly. As the audio frequency increases, the frequency varies more rapidly. Increases in the volume cause a greater change in the frequency.

In other words, the rate of change of the frequency is determined by the a-f input, whereas the amount of the frequency change is controlled by the volume of the audio signal. This is illustrated in Fig. 225. In part (*a*) of this figure, the audio frequency is low and the frequency of the carrier changes slowly. The volume of the audio input is also low so there is only a small change in the frequency. In part (*b*) the audio frequency is higher; consequently, the frequency of the carrier changes more rapidly and since the volume of the audio signal is higher

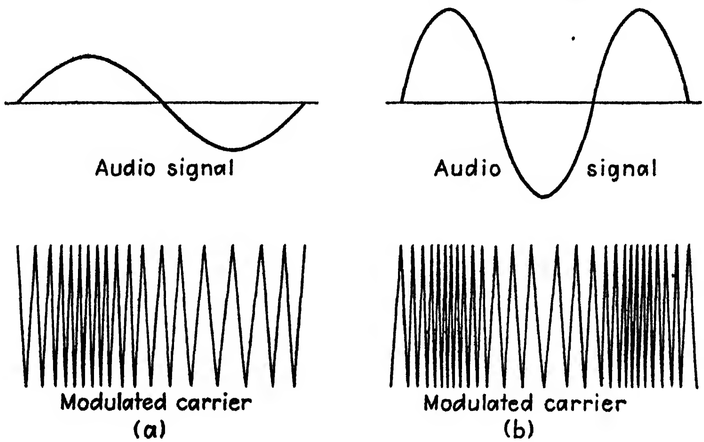


Fig. 225.—A frequency-modulated radio wave.

there is a greater change in the frequency. Of course the rate of change of the frequency—the audio frequency—is independent of the amount of the change—the volume. Either may vary without the other. Note that the amplitude in Fig. 225 does not vary.

Frequency-modulated Radio Circuit.—The foregoing brief explanation shows that the signal at the receiver will have substantially constant amplitude but will vary in frequency over a band of 150 kc. This contrasts with an amplitude-modulated signal, in which the band is never more than 20 kc. and usually not over 10 kc. wide. This of course means that the frequency-modulated radio must have a much wider tuning curve. Band-pass circuits are used and, again in contrast to the procedure in amplitude-modulated radios, resistors are put either in series or in parallel with the tuned circuits to make them broad.

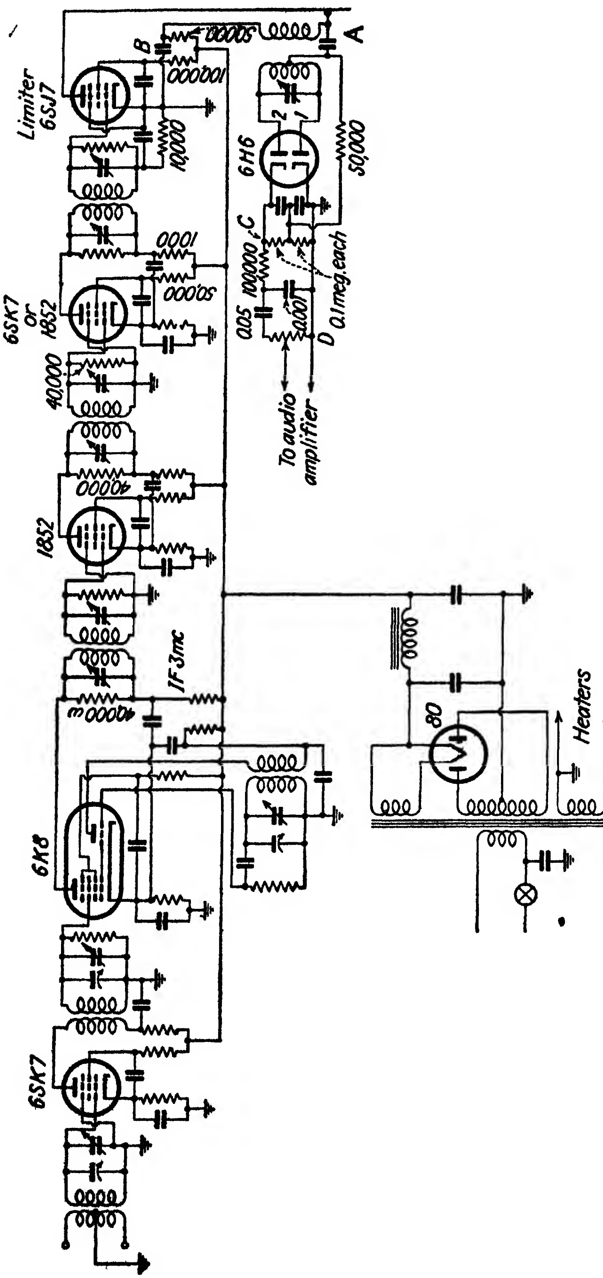


FIG. 226. —A schematic diagram of a frequency-modulated radio.

Figure 226 shows the schematic diagram of a frequency-modulated radio. It consists of a 6SK7 r-f amplifier, a 6K8 first detector-oscillator, two 1852's for i-f amplifiers, a 6SJ7 limiter, and a 6H6 second detector. The audio amplifier is not shown for it is just a standard high-quality resistance-coupled amplifier, which has already been discussed.

It can be seen that the r-f, first detector, oscillator, and i-f circuits are the same as in a standard AM set with the exception of the resistors across the tuned circuits to broaden them out.

Limiter.—The circuit of the limiter is like one of the i-f stages, the only difference being the plate and screen-grid voltages

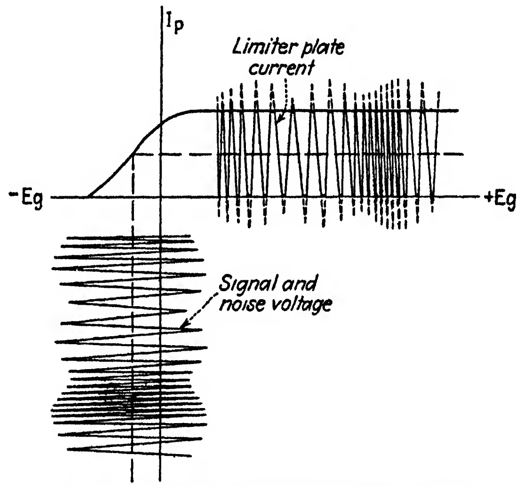


Fig. 227.—Diagram illustrating limiter action.

applied to the tube. These are much lower on the limiter stage. This is done to cause the stage to overload with even a normal signal.

It has been found that practically all static, both natural and man-made, is amplitude-modulated. The purpose of the limiter stage is to prevent any amplitude modulation from getting to the second detector. Figure 227 illustrates how it does this. The signal is frequency-modulated by the desired program and amplitude-modulated by electrical disturbances.

The plate and the screen-grid voltage are very low. This means that the maximum plate current will be low and that the cut-off point will be reached with a comparatively low bias

voltage. It will be also noted that a sharp cut-off tube is used in the limiter stage to obtain this result. If the signal is large enough to overload the tube, then all of the amplitude modulation—the noise—will be lost for the plate current can go neither up nor down far enough to reproduce the amplitude variations of the grid signal. The frequency of the plate current, however, will be an exact duplicate of the grid signal. The larger the signal applied to the grid of the limiter, the less chance there is for any amplitude-modulated noise to get through. And again we have a contrast between an amplitude- and a frequency-modulated radio. In an amplitude-modulated radio an increase in the sensitivity always increases its noise-picking-up ability, whereas in a frequency-modulated radio the reverse is true. An increase in the sensitivity increases the signal on the limiter grid and this results in a decrease in the noise output.

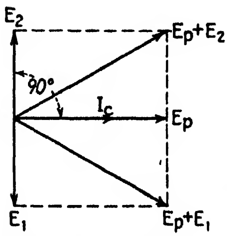
Second Detector.—The circuit of the second detector is like the discriminator of the a.f.c. circuit shown in Fig. 191 except that the r-f choke is replaced by a 50,000-ohm resistor.

In order to understand how this circuit can reproduce the audio frequencies from the frequency-modulated i-f signal we shall consider the voltages applied to the diode plates under three conditions: (1) when the frequency is at its normal or unmodulated value, (2) at a frequency above this, and (3) at a frequency below this value.

Both the primary and the secondary of the transformer are tuned to the unmodulated value of the signal. When the signal is unmodulated or at the middle of its swing, the primary and the secondary of the transformer are at resonance. The primary voltage E_p is applied to both the diode plates through the condenser *A* (Fig. 226), which has practically no impedance at the signal frequency. Since the secondary is inductively coupled to the primary, the primary flux will induce a voltage E_s in the secondary. E_p and E_s will be in phase because they are induced by the same flux. The voltage E_s causes current to flow in the tuned circuit and, since it is at resonance (inductive and capacitive reactance canceled), the circulating current I_c will be in phase with E_s and also with E_p. However, the voltage across a coil is always 90 deg. ahead of the current through the coil, so E_c is 90 deg. ahead of I_c. But the secondary is center-tapped so that the voltages on the two halves will be equal and

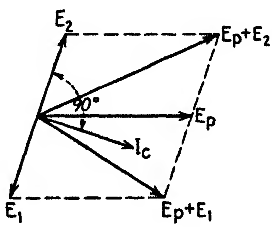
180 deg. out of phase with each other. This means that when the voltage is positive on one diode it will be negative on the other. The voltage on one half of the coil E_1 will be 90 deg. ahead of E_p, while the voltage E_2 on the other half will be 180 deg. behind E_1 or 90 deg. behind E_p. One diode then has $E_p + E_1$ on it, while the other has $E_p + E_2$ on it. This is illustrated in Fig. 228.

Since the i-f voltages on the two diode plates are equal, the d-c voltages on the two diode-load resistors are equal and, since they are connected in series bucking, they will cancel each other and the voltage from point C (Fig. 226) to ground will be 0.



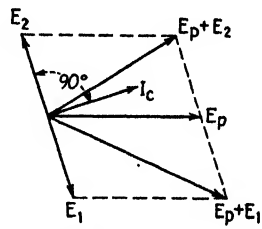
Vector diagram when the frequency is at its normal value

FIG. 228.



Vector diagram when the frequency is above resonance

FIG. 229.



Vector diagram when the frequency is below resonance

FIG. 230.

When the incoming signal is above the resonant frequency of the transformer, the impedance of the tuned circuit is inductive and I_c lags behind E_s and E_p. E_c, or half of it, E_2 looking from the center tap would be 90 deg. ahead of I_c but, since I_c lags E_p, E_2 will be less than 90 deg. ahead of E_p. This is illustrated in Fig. 229. It can be seen that the voltage $E_p + E_2$ on diode 2 is greater than $E_p + E_1$ on diode 1.

When the signal frequency is below the resonant frequency of the tuned circuit, the impedance of the tuned circuit is capacitive. I_c will therefore lead E_s and E_p. The effect of this change is shown in Fig. 230. Under these conditions the voltage on diode 1 is the greater.

It will be remembered that during the positive half cycle of the audio input to the transmitter the r-f output frequency was high. High frequency causes the voltage on diode 2 to be higher and the d-c voltage on its load resistor will be higher, therefore point C will be positive in respect to ground. During the nega-

tive half cycle of the transmitter audio input, the frequency is low; consequently, the voltage on diode 1 is greater and the d-c voltage on its load resistor will make point C negative. The a-f cycle will, therefore, be reproduced across the volume control D.

Automatic Volume Control in FM Sets.—There is very little need for an a.v.c. circuit in a frequency-modulated radio because the limiter supplies a signal to the second detector of constant amplitude providing the signal applied to its grid is large enough. An a.v.c. circuit might even interfere with the action of the limiter by reducing the amplitude of the weaker signals to a point below that required for the limiter grid.

REVIEW QUESTIONS

13-1. What is meant by modulation?
13-2. Why are resistors put across the tuned circuits of FM receivers?
13-3. Explain the action of the limiter stage.
13-4. What is the purpose of the limiter stage?
13-5. Show a diagram of the second detector of an FM receiver
13-6. Explain the operation of the second detector of an FM receiver.
13-7. Why is a.v.c. seldom used on FM receivers?

CHAPTER XIV

SERVICING RADIO RECEIVERS

Radio Soldering.—The ability to make a good solder joint is of the utmost importance to the radio serviceman. Solder joints in a radio set must be perfect electrically and strong mechanically. Poor joints cause noisy reception, broad tuning if in tuned circuits, intermittent operation, or complete loss of the program.

Much embarrassment has been caused by a receiver failing to work after delivery, because of the breaking of a poorly made joint that could not withstand jarring during delivery. To avoid this difficulty, remove the tubes and set the receiver down on the bench rather roughly a few times. If the joints can stand this treatment, it is safe to assume that they will survive the delivery handling. Many of the large manufacturers have a special jiggling machine for this purpose and test every set before it leaves the factory.

The following information will be of assistance in making a satisfactory solder joint:

1. *Preparing the Parts to Be Soldered.*—The parts to be united—the wire, the lug, the sheet metal, etc.—must be scraped down to bare metal. All scale, rust, or oxidation must be removed. This work must be done thoroughly. Even tinned wire and lugs that have lost their first bright shine should be scraped carefully.

2. *Flux.*—Heat causes oxide to form rapidly. To prevent this during the soldering process, a flux is used. An oxide is a chemical combination of the oxygen in the air and the metal. The flux, which must be a substance lacking in free oxygen, flows over the metal and prevents the oxygen from reaching it. It is essential that the proper flux be used. The choice of flux depends on the material to be soldered and on the type of equipment in which the material is used. For radio-circuit soldering, only rosin should be employed. The most convenient form is

rosin-cored solder. For heavier work, such as No. 14 wire or ground connections to pipes, a noncorrosive rosin-soldering paste may be used. This is not recommended for radio-chassis soldering, because the excess paste left around the joint collects dust and moisture which often contains acid. This is especially true in cities. This acid attacks the joint and creates either a noisy joint or an open circuit. For use on sheet iron, hydrochloric acid, also called muriatic acid, cut with zinc is used. The joint should be carefully washed off with alcohol or benzine to remove all traces of the acid; otherwise corrosion is sure to follow.

3. *The Soldering Iron.*—Much poor soldering is caused by the use of an iron of the wrong size for the work. The materials

Fig. 231.—Soldered joints, the upper one good, the lower one very bad.

being soldered must be hot enough to melt the solder. A drop or two of solder between the parts and the iron greatly quickens the transfer of heat from the iron to the material. A 100-watt electric iron is a convenient and satisfactory size for radio-circuit work. For soldering grounds on the chassis, a heavier iron is usually necessary, because the sheet metal conducts the heat away so rapidly that the smaller irons cannot supply it fast enough to get the material sufficiently hot. In constructing a chassis or shields from sheet copper, a 5-lb. tinsmith's iron is

necessary, for copper is a very good conductor of heat and requires a large iron to raise it to a soldering temperature.

If the joint is properly made, the solder will flow out to a very thin edge. If the solder takes a globular shape, it indicates that the joint is not properly made. The globular shape may be caused by insufficient cleaning, improper flux, or insufficient heat. Examples of good and bad solder joints are shown in Fig. 231.

Trouble Shooting.—The aim in all trouble shooting should be to determine as quickly as possible the section of the equipment that is out of order. There are a large number of small indications that tell the experienced trouble shooter where to look for the difficulty.

It is impossible to set up a servicing routine that can be followed with every set because of the great number of different difficulties that the various sets may have. If a routine were devised, it would have to include tests for all kinds of trouble and would require making many tests that were unnecessary. However, there are certain operations that should be performed on all sets. Every set should be thoroughly cleaned. If this is attended to at the start, two advantages will be achieved: (1) You will have a clean set to work on and (2) you can give the set a careful visual inspection during the cleaning. Many little signs can be found that will indicate trouble: the condition of the electrolytic condensers, whether they are discolored and bulging, if paper covered, and whether they have a salt incrustation on them if they are aluminum cans; burned or blistered resistors; or the presence of wax from some condenser or transformer. These can all point definitely to the trouble. And all these indications can be noticed while the set is being cleaned, and should indicate to the serviceman the correct procedure to follow. In many cases no test equipment will be necessary to find or repair the trouble. Under these circumstances the use of test equipment is definitely a waste of time.

If the serviceman comes in contact with the owner of the set when it is brought to the shop, he can often determine the difficulty by asking a few questions. For example, ask how the set performed just before it stopped. If the answer is that "the set was all right last evening but when we turned it on today it would not play," the trouble is probably a blown condenser.

No doubt the condenser was weak and could not survive the extra voltage put on it during the warm-up period before the plates began to draw current. If the answer is "We used to be able to get distant stations but lately all we can hear is the powerful local ones," then worn-out tubes are indicated. In any case the particular difficulty that caused the set to be brought in should be known. The author learned of one case where a serviceman spent two days endeavoring to find something wrong with a set. He let the set play the two days and finally gave up. Later he learned that the complaint was that the set was noisy between 7:00 and 7:30 A.M. only. There was a new electric razor in the family! A few questions at the beginning would have saved a great deal of trouble in this instance. If the set is reported to be completely dead, a quick look at the filter condensers might show the trouble immediately.

Servicing then should start with a visual inspection of the set and with a technical evaluation of the remarks made by the owner. But often neither of these gives any usable information. Then the serviceman must rely on the use of test equipment.

Test Equipment.—Every serviceman should have test equipment that is suited to his own shop. Just what that equipment should consist of depends on the type of set he usually works on, his method of servicing, whether he does work in homes or entirely in a shop, and many other factors. From the standpoint of the beginner with a limited amount of funds to start with probably the best buy is a combination volt-ohm-milliammeter. This will enable him to find and repair more difficulties than any other single piece of equipment. The next piece of equipment should be an all-band test oscillator. The a-c scales on the voltmeter can be used as an output meter. The author has found that a pair of 8-mf. high-voltage paper condensers with attached leads and alligator clips is very convenient on the bench. If a customer is waiting for an estimate, the condensers can be substituted for bad filter condensers and it can be quickly determined whether there is anything further wrong with the set. If you are looking for the source of hum or a microphonic tube, which sometimes causes trouble even when another tube is tapped, the difficulty can be quickly located by shorting each of the grids in the circuit by connecting the condenser from grid to ground. The condensers can be

used as a temporary substitute for almost any condenser in the set. This is particularly true if the condensers are noninductively wound. One point should be remembered and that is that these condensers will hold a charge and must be discharged after they have been put across high voltage. If they are put across a plate circuit and then across the grid circuit of a tube, a new voice coil may be needed in the loud-speaker.

For locating the trouble in a dead set, a Chanalyst or Analyst is very convenient, but a simple audio oscillator, such as is shown in Fig. 232, and the test oscillator and output meter will work quite satisfactorily.

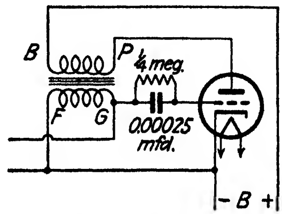


Fig. 232.—Circuit diagram of a simple audio oscillator.

This oscillator will put out a single audio note. When a voltage check shows that the power supply of a dead set is in working order, the leads from the test audio oscillator should be put across the grid circuit of the first audio tube. If the audio amplifier and the loud-speaker are in working order, the signal will be heard in the loud-speaker. If the signal does not come through, try the grid of the second tube and so on toward the loud-speaker. The trouble of course is just ahead of the first location where the signal comes through. If the audio amplifier is working, the r-f i-f test oscillator should then be tuned to the intermediate frequency and its output leads put across the grid circuit of the first detector. When the oscillator is modulated, the signal should be heard in the loud-speaker. If it is not, move the test leads to the grid circuit of the next tube toward the second detector. In this way any trouble in the i-f amplifier can be located. Next the dial of the set should be turned to the location of some powerful local station. The test oscillator should then be tuned to the frequency that the set oscillator should be on for that station. The output leads of the oscillator are then connected across the output circuit of the oscillator in the set. If the set is dead because of oscillator failure, the station should come in with a little resetting of the test oscillator and set dials. By this method the particular tube or stage that is causing the trouble can be located very quickly. The two oscillators, audio and r-f i-f, should be mounted on the bench and arranged so that they can be put into operation by the

flip of a switch. Each should have test leads attached, which should be kept in working order.

Any other audio signal can be substituted for the oscillator, such as a phonograph pickup. The main thing to achieve is to have the signal available without spending a lot of time hooking it up.

Use of Voltmeter.—Good judgment should be used in interpreting the voltage readings made on resistance-coupled circuits. The following example will show the necessity for this. Suppose that the plate voltage of the detector shown in Fig. 233 is being obtained with a 1,000 ohm per volt instrument. The detector normally draws 0.2 ma. of plate current. The B supply is 250 volts and the plate resistor 100,000 ohms. Without the instrument connected, the current through the plate resistor is only 0.2 ma. The drop in the resistor can be found from the formula $E = IR$ or $0.0002 \times 100{,}000$, which gives 20 volts. There will be a voltage of 250 − 20, or 230, volts actually on the detector plate. But if an instrument is connected from the plate to the cathode to read this voltage, the current used by the instrument also passes through the plate resistor, and, since this current often is over 0.5 ma., the drop in the plate resistor will be several times its normal value and the indicated reading will be far below the true voltage.

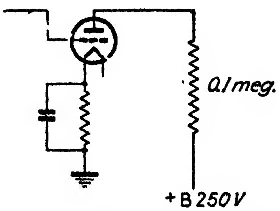


FIG. 233.—Circuit diagram illustrating the difficulty in reading the plate voltage of a resistance-coupled tube.

Many difficulties are made very evident by a voltage check. For instance, if no voltages, either A, B, or C, are found in an a-c set, the trouble must be in the power transformer or in the supply cord, whereas if only the B and C voltages are missing, the trouble is more likely to be in the rectifier or in the filter of the B power supply. Low- or no-plate or screen-grid voltage can be caused by leaky or shorted by-pass condensers in the plate or the screen-gird circuits. No control-grid voltage might be caused by an open circuit or, if a C bias resistor is used, a shorted by-pass condenser across the resistor might be the cause. Abnormal voltages are often caused by resistors changing their value on account of aging or the heat to which they have been subjected in the set. Resistors in circuits showing abnormal

voltage should be checked against the values shown in the circuit diagram. If no diagram is available, the serviceman must rely on his knowledge of the usual values used for the particular purpose in other receivers.

Tube Checking.[1]—The most common difficulty in radio sets is defective tubes; therefore, the next step in locating trouble is to check the tubes thoroughly. Tubes should always be tested for shorts first. This may avoid blowing fuses in the tube checkers or damaging the instruments in them. The short checker will also detect many defective tubes that the tube checkers may pass as satisfactory.

Most tube testers can be classified in two groups. One type is known as an "emission" tester. It relies on the fact that if a tube is beginning to weaken it must have been in service long enough so that the emission of electrons from the heater is beginning to lessen. In a large percentage of cases, this is true; h wever, there are many cases where the emission may be perfectly satisfactory and the tube will be unsatisfactory because, for instance, the grid may be disconnected internally and therefore a change of the grid bias will not change the plate current. In many of the testers of this type, all the elements of the tube are tied together and act as a plate to collect the emission. In this case, if some of the elements were disconnected or shorted, no indication of the condition would be given. Testing each element separately, *i.e.*, using each element separately as a plate, will overcome this difficulty.

The second type of tube tester is known as a "mutual-conductance" tester. In this tester, a fixed plate voltage is put on the tube and the grid bias changed a fixed amount. The corresponding change in the plate current gives a measure of the worth of the tube. This test more nearly duplicates the operating conditions of the tube and so will detect on the average more defective tubes than the emission testers. One objection to this type of tester is that it becomes very complicated when it is arranged to test all the receiving tubes on the market. This method is also unsatisfactory unless the tube is tested with the same plate and grid voltages that it has in the equipment in which it is used.

[1] See the section on "Tube Testing" at the end of the "RCA Receiving Tube Manual."

At least one tube tester on the market is known as a "dynamic mutual-conductance tester." This tester attempts to reproduce the operating conditions in the equipment in which the tube is used. It places the voltages recommended by the tube manufacturers on the plate, grid, and other elements of the tube and then applies an a-c signal to the grid. The power output is then a measure of the worth of the tube. This method is most satisfactory, provided the tube has the same voltages applied to it that it has when in use.

If the tube is of the heater-cathode type, it should be checked for cathode leakage. This is particularly important in the tubes used in the universal sets, for cathode leakage in one of these tubes often shorts some of them out of the circuit, thereby decreasing the resistance in the circuit and increasing the current in the remainder to such an extent that they burn out. Sometimes a tube will show a short circuit only when it is at a particular temperature. This is due to the expansion and contraction caused by the variation in the temperature of the metal parts inside the tube. It is a good plan, while testing, to tap the tube with the hand or a small rubber mallet to see if any unusual indication is given. Occasionally tubes are found that will check perfectly and yet will not operate satisfactorily in the set. This may be due to the fact that they are operating on a portion of their characteristic not covered in the test or with voltages much higher than those used in the test. The tube manual of one of the large tube manufacturers states that it is not possible to construct a tube checker that will pick out all the defective tubes. It is safe to consider bad any tube that the tube checker so indicates, but if the checker indicates a good tube, in a few cases it may not be such. The tube checker, therefore, eliminates only most of the bad tubes. Mercury-vapor tubes normally show a bluish-white glow due to the gas present in the bulb. This glow between the plate and cathode or heater in any other tube indicates the presence of gas in the tube also, but, in this case, it may be very harmful because it allows much more current to flow than under normal conditions. This excessive current may damage the primary of the transformer connected to the tube or even the power supply. A glow near the glass of some tubes is caused by fluorescent materials (similar to that used in a

cathode-ray tube) in the glass and does not interfere in any way with the operation of the tube.

Special Cases.—There are a number of unusual difficulties that require special treatment. First there is the set with the burned-out but not open antenna coil. This is usually caused by lightning. Checking with an ohmmeter may not reveal the difficulty, for the true resistance and the shorted resistance may be very nearly alike. Both may be a fraction of an ohm. One good test for this trouble is the use of a vacuum-tube voltmeter to measure the signal voltage across the coil when a test oscillator is connected across it. If a vacuum-tube voltmeter is not available, usually a close visual inspection of the coil will reveal the trouble.

At the opposite end of the set is a voice coil that sometimes opens up. A check with the ohmmeter will show nothing unless the output transformer is disconnected. And then there is the case of the voice coil that has been pushed off the form by a heavy overload and is packed down in the bottom of the slot. This may test open, or not, but in either case the speaker will not work. The only way to check this difficulty is to take the cone out. Occasionally one or two turns of the coil will get loose and cause a bad rattle. This can be found only by removing the voice coil from the speaker and giving it a very careful inspection. Speaker cement should be used to fasten the loose turns in place.

Tuning condensers occasionally short at one or more points in their movement. This usually results in a great deal of noise in the loud-speaker when that point is reached. The trouble with this difficulty is usually to get sufficient light through the condenser to see where it is touching. Sometimes a white paper put under the condenser will reflect enough light so the trouble can be found. A small pilot light at the end of a flexible cord is a great help, provided the light will go under the condenser or behind it. If the condenser can be removed from the set easily, the shorting spot can be located by putting the condenser, in series with a current-limiting light bulb, across the lighting circuit. Sparking will tell where the difficulty lies. Remember to look at the equalizing condenser connected across the tuning condenser. The mica insulator in these occasionally cracks or falls out, thereby causing a short. This difficulty is most

easily found with some form of signal-tracing equipment as described for use with a dead set. A shorted tuning or equalizing condenser will result in a dead set.

Once in a while a set turns up that has been worked on at home or on which auto-repairing methods have been tried; *i.e.*, going over the whole set and tightening all the screws. Let us hope that all it needs is realignment, but remember to look for bad solder connections, crossed wires, and wrong connections.

Fixed Condensers and Resistors.—Practically all the troubles in the radio-receiver circuits are due to faulty resistors and condensers. Most of the resistors are made of a carbon composition. One of the characteristics of this type of resistor is that it will change its resistance as it ages. Also its resistance frequently changes when the resistor is subjected to heat. If the value of a resistor changes more than approximately 10 per cent of its original value, the circuit of which it is a part will operate in a defective manner. This will be more apparent in some circuits than in others.

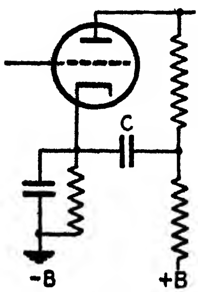


FIG. 234.—Circuit diagram of a resistance-coupled amplifier tube illustrating the damage that is caused by the shorting of a plate by-pass condenser.

Any resistor that has been subjected to a severe overload (*e.g.*, a cathode resistor when a plate by-pass condenser becomes shorted) should be replaced even if it checks satisfactorily. It may cause noise and there is also the possibility that it may cause trouble in a short time. The condition is shown in Fig. 234. It can be seen from the diagram that, if the plate by-pass condenser *C* is shorted, the plate voltage is applied directly across the *C* bias resistor and, as this is usually 2,000 ohms or less, excessive current will be forced through the resistor. It can also be seen that high voltage will be applied across the *C* bias by-pass condenser, and this should also be changed.

Occasionally a resistor is found that will test satisfactorily when it is cold but will test open when it is warm. This is caused by the fact that the resistor expands as it warms up and may open the circuit. This reduces the heating, and the resistor contracts and makes contact again. The cycle then starts over again. The time necessary for the cycle may vary from a frac-

tion of a minute to several hours. In stubborn cases of intermittent operation, it is sometimes helpful to speed up the heating by up-ending the chassis in front of an electric heater. Milliammeters in the plate circuits of the tubes will be an aid in detecting the stage that has the intermittent resistor.

A low-voltage continuity checker is not satisfactory for checking condensers. It sometimes happens that the impregnating compound in the condenser does not fill all the spaces between the foil and the paper. In case of a puncture at such a place, low voltage often does not indicate the fault. When higher voltage is used, the opposite charges on the plates attract each other and pull the plates together, thus causing the short. The resistance of good fixed paper or mica condensers should be above 75 megohms per microfarad. Several good condenser checkers are discussed in Chap. IV.

Electrolytic condensers normally have a leakage of 0.1 to 0.5 ma. per microfarad. When the current at rated voltage varies to any extent from these values, the condenser should be replaced. Either higher or lower values of leakage current indicate that the filtering efficiency of the condenser is impaired. Electrolytic condensers can also be checked with an ohmmeter. When the positive lead of the ohmmeter is connected to the positive terminal of the condenser, a power-supply filter condenser should have at least 400,000 ohms resistance; all the other electrolytic condensers in a receiver should have over 100,000 ohms resistance.

Aligning T.R.F. Receivers.—Because of unavoidable variations in the tuning condensers, coils, and connections of the several stages, some method of compensating for them must be used. There are two methods of equalizing ganged condensers: In the first method, very small adjustable condensers are connected in parallel with the tuning condensers. This method allows the exact equalization of the stages at only one frequency. Usually equalization will be satisfactory over the rest of the band. In the second method, equalization is secured by slightly bending the end plates of the rotors of the condensers, which are slotted radially, forming five or six sections. By this method, the condensers can be accurately equalized at five or six points in the broadcast band. The need of equalization is indicated by low volume and broad tuning.

Procedure for Equalizing Ganged Condensers.—Always turn a set on for at least 10 min. to let it warm up before any attempt is made to adjust it.

Tuning Wand.—If the tuning inductances are exposed, the use of a tuning wand enables the serviceman to determine very quickly whether or not the stage needs equalizing. With the test oscillator connected to the antenna and ground posts and adjusted to obtain a low reading on an output meter, the introduction of either end of the wand should lower the output meter reading. If one end raises the reading and the other lowers it, the indications are that the stage is out of adjustment and the following procedure should be adopted:

If the set has a.v.c., the reading of an output meter connected in the audio circuits will be unreliable because the a.v.c. will tend to keep the audio output at a constant level regardless of the accuracy of the tuning. If it is necessary to use an audio-type output meter, the action of the a.v.c. circuit should be stopped unless the signal from the test oscillator is attenuated to a value so low that it will not cause the a.v.c. to operate. The a.v.c. tube should never be removed for this purpose. When a separate a.v.c. tube is used, a simple method of stopping the a.v.c. action is to slip a soda straw or a piece of adhesive paper over one of the filament or heater prongs of the tube. When the a.v.c. tube is a double-purpose tube, the easiest method is to remove the a.v.c. line from the diode-load resistor and ground it. If the controlled tubes have no bias resistors to provide a minimum bias, some method should be used to supply this while the equalizing procedure is followed. One method of doing this is to connect a high-resistance potentiometer across a *B* battery and adjust the arm to the proper point to get the bias desired. The positive side of the battery is grounded and the arm of the potentiometer connected to the a.v.c. line. In some circuits, the line feeding the signal to the diode providing the a.v.c. can be disconnected. This is usually the case when a separate diode is used for the a.v.c. circuit.

The objection to this method is that, unless careful precautions are taken, the controlled tubes will be operating on a different portion of their characteristic curve during the alignment procedure than they will in actual operation and this will cause misalignment. A much better method is to feed a normal signal

tube, a resistor of about 100,000 ohms should be connected between the plate of the tube and the $+B$ lead and the transformer or choke disconnected. The oscilloscope should be connected across the resistor.

A preliminary alignment of the i-f amplifier should be made by connecting the oscillator tuned to the proper i-f frequency with its frequency modulation off but the amplitude modulation on. This should produce the a-f pattern on the oscilloscope screen. Starting with the secondary of the last i-f transformer all the padders should be adjusted to make the pattern on the screen as high as possible. This assures having the amplifier tuned to the proper frequency. The amplitude modulation should

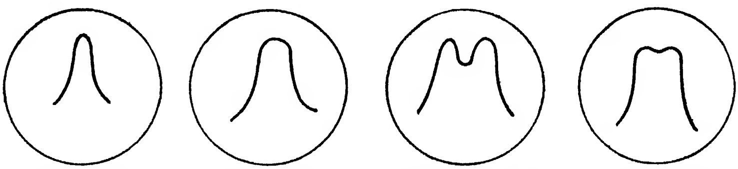


FIG. 235.—Oscilloscope tracings of the frequency characteristics of an i-f amplifier.

then be turned off and the frequency modulation turned on. If the frequency modulation is obtained by a rotating condenser, the main tuning condenser of the oscillator will have to be reduced in size—tuned to a higher frequency—in order to compensate for the capacity of the motor-driven condenser in parallel with it. As this condenser is tuned, two tuning curves will appear on opposite sides of the screen and approach each other. The tuning should continue until the curves coincide at the peaks at least. Some motor-driven condensers are arranged to short the output when the condenser is opening. This produces a single pattern on the screen as the condenser closes.

The tuning condensers of the receiver should then be moved to see if there is any external pickup that might be influencing the picture on the screen. If this is occurring, it usually may be stopped by shorting the antenna and ground leads or by shorting the oscillator grid or plate coils. The padding condensers across the i-f coils, beginning with the last, can now be adjusted to obtain the desired curve. This will vary in different receivers. In general, the top of the curve should be kept as broad as

possible to ensure the best possible h-f response. Care should also be taken to avoid too great a dip between a double-peaked curve, for this will reduce the l-f response. The proper and improper curves are shown in Fig. 235.

It is not absolutely necessary to make the a.v.c. circuits ineffective, because the frequency changes so fast that a.v.c. action ordinarily does not interfere with alignment.

Oscillator Alignment.—The oscillators in the modern superheterodyne sets are usually made to track (maintain a fixed frequency difference from the r-f circuits) by one of two methods. Sometimes the oscillator-tuning condenser has specially shaped plates, but a common method is by a circuit, shown in Fig. 236.

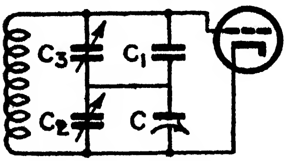


FIG. 236.—Oscillator-tuning circuit used in superheterodyne receivers.

In this circuit, the tuning condenser C is identical with the r-f tuning condensers. The series condenser C_1 usually has about twice the capacity of the tuning condenser. The padding condenser C_2 is used to align the oscillator at the h-f end of the band, and the padding condenser C_3 takes care of the l-f end of the band. When a test oscillator or signal generator and an output meter are to be used, the oscillator circuit is aligned by tuning the test oscillator to the h-f end of the band and, after the set has thoroughly warmed up, adjusting the condenser C_2 for maximum output. The tuning condenser gang should be rocked back and forth during this adjustment. Then tune in the test oscillator at the l-f end of the band and adjust the condenser C_3 for maximum output. The condenser should be rocked during this adjustment also. This rocking of the condenser is necessary because maximum output is obtained when the r-f and the oscillator circuits are both properly tuned with one setting of the condenser gang. If rocking the condenser is awkward owing to the location of the trimmers, the same result can be reached by adjusting the oscillator padder for maximum output. Then adjust the tuning condenser for maximum output. Again reset the padder for maximum output and then the tuning condenser. Continue this procedure until the highest output is reached.

In many modern receivers the oscillator uses an iron-cored coil. This increases the stability of the oscillator. The circuit is shown in Fig. 237. The l-f adjustment is made by moving

the core in the coil. The h-f adjustment is a trimmer across the oscillator-tuning condenser as in the first circuit. The alignment procedure is the same for either circuit.

The frequencies 600 kc. and 1,400 kc. are often used for this purpose in the broadcast band, because, if the extreme ends of the band are used, the tracking in the middle of the band may be too far out. When specially shaped plates are used on the oscillator condenser, the only adjustment that is necessary is an equalizing condenser across the tuning condenser. This is adjusted for maximum output.

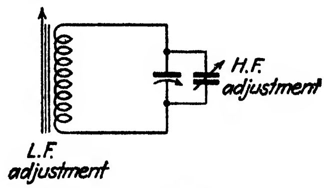


FIG. 237.—An oscillator-tuning circuit using an iron-cored inductance.

If the cathode-ray oscilloscope is used to align the oscillator circuits, it should be connected to the detector as explained for i-f amplifier alignment. The leads from the amplitude-modulated oscillator should be connected to the antenna and ground connections of the receiver. The test oscillator is then tuned to 1,400 kc., and then the receiver tuned to the oscillator. The oscillator-circuit adjustments are made while the receiver-tuning condenser is being rocked back and forth. When the 1,400-kc. adjustment is satisfactory the procedure should be repeated with the test oscillator set at 600 kc.

Multivibrator.—[1]A multivibrator, which consists of a two-stage resistance-coupled amplifier with a positive feedback, is

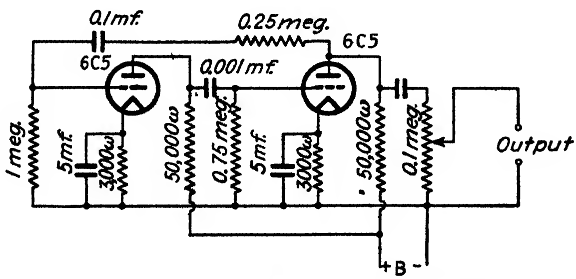


FIG. 238.—Circuit diagram of a multivibrator.

very convenient to use in place of the test oscillator in adjusting oscillator circuits. With this equipment, it is not necessary to rock the condenser gang. The circuit of a multivibrator is shown in Fig. 238.

The values of the plate and grid resistors and the blocking condensers in this circuit are chosen so that the multivibrator oscillates at a fundamental frequency of 400 cycles and at all the harmonics of 400 cycles up to about 20 mc.

Difficulty is often experienced in attempting to align the oscillator at the h-f end of the bands, especially the highest frequency band when a pentagrid converter is used as a detector oscillator. This is due to the coupling between the r-f and the oscillator grids. A resistor of approximately 50 ohms connected in series with the signal grid (No. 4) and the tuned circuit will clear up the difficulty.

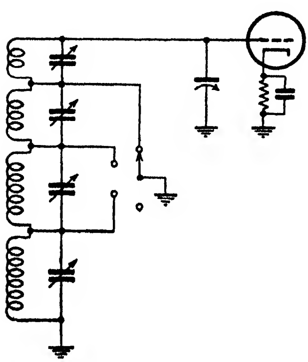


Fig. 239.—Circuit diagram showing coils for four bands in series.

Alignment of the Radio-frequency Circuits.—The alignment of the r-f circuits can be carried out by the oscillator-output meter or the cathode-ray oscilloscope method. For the broadcast band, the padding condensers are usually mounted on the tuning condensers. When the receiver covers more than one band, it will be found that each r-f and oscillator coil has its own trimmer. It is quite essential that the frequency to which each coil should be adjusted be known, or very little can be accomplished by attempting to adjust the padders. In some receivers the coils for each band are independent of each other. In this case the order of alignment is of no consequence. However, in some receivers the coils are all in series, or consist of a single tapped coil as shown in Fig. 239. When this is so, the highest frequency coil should be aligned first and the rest in order, finishing with the lowest.

The following brief notes bring out the main points to observe in the alignment of superheterodyne receivers:

1. Keep the output of the best oscillator at a low level unless definitely told to raise it.

2. Always short the oscillator or otherwise prevent any signal except the test oscillator getting into the intermediate frequency when aligning it. Be sure to have the test oscillator set to the correct frequency. Check the accuracy of the calibration frequently.

3. When an output meter is used as an indicator, a modulated input, either r-f or i-f, is required to obtain an indication. When a cathode-ray oscilloscope is used, the input should be unmodulated. The use of a modulated signal with the oscilloscope causes the trace to be blurred or to have the audio wave continually moving along the trace.

4. Always feed the r-f signal into the set through the dummy antenna specified by the receiver manufacturer.

5. Always align the receiver at the frequencies specified by the manufacturer.

6. Always go through the alignment procedure the second time to prevent any reaction that one circuit might have on another from upsetting the accuracy of the final setting.

7. Always follow the manufacturer's specifications for alignment if they are available even if they seem needlessly complicated or unusual.

Servicing Frequency-modulated Radios.—Since the r-f, i-f, and oscillator circuits of FM and AM sets are practically the same, the same difficulties with poor tubes, by-pass condensers, and resistors will be found in both types of sets. However, owing to the peculiarities of the FM circuits, there are certain points that need to be emphasized. Many of the i-f transformers have resistors across either the primary or secondary or both to broaden out the tuning curve, but these same resistors cut the gain and therefore have a tendency to prevent oscillation. If one of these resistors should increase in resistance or become open-circuited, the tuning would be much sharper and the gain would go up possibly high enough to cause oscillation. On the other hand if the resistance were decreased, the gain would be lowered. This might prevent the limiter from operating properly and result in noise in the output. Any other item such as weak tubes, improper operating voltages, and a poor antenna system would also lower the gain ahead of the limiter and tend to allow noise to get through.

Distortion is caused by practically the same difficulties in both types of sets. Among the causes are misalignment of any of the tuned circuits, oscillator drift, regeneration, and defective parts.

The power supply and the audio sections of both sets are identical so they need not be mentioned here.

Alignment of Frequency-modulated Radios.—There are several methods of aligning frequency-modulated radios requiring a wide variety of equipment. Although visual alignment with a wide-band frequency-modulated oscillator and a cathode-ray oscilloscope is probably the fastest and the most accurate method, it requires equipment that is not often available. By taking a reasonable amount of time and care a perfectly satisfactory alignment can be accomplished with the equipment found in any good serviceman's possession. The order of alignment is the same in an FM set as it is in an AM set. The i-f amplifier is aligned first beginning with the last stage, which in the case of the FM set is the limiter. The other i-f stages are then aligned and then the oscillator and r-f stages.

Alignment with an Unmodulated Test Oscillator and Output Indicator.—Since an unmodulated oscillator is used and, in fact, even if it were amplitude-modulated, no signal would get to the audio amplifier. Therefore it is impossible to use an audio type of output meter. The usual method of measuring the output is to take advantage of the fact that the limiter grid draws current and that this current is proportional to the output. All that is necessary is to measure the grid current. This can be done directly by inserting a meter with a 0–1 ma. or lower scale in the grid circuit, preferably at the ground end. The meter leads should be twisted. In many circuits there are load resistors; in that case a high-impedance voltmeter, such as an electronic voltmeter, or even a meter with 20,000 ohms per volt can be connected across one of the resistors. In circuits not having load resistors, a resistor of about 1,000 ohms can be connected between the lower potential end of the coil and ground to connect the voltmeter across. The electronic voltmeter can also be connected to the grid of the tube and the strength of the signal measured directly.

The oscillator is connected in the normal manner to the grid of the tube ahead of the transformer being adjusted. When the limiter transformer has been aligned, the oscillator is moved up one stage, the output indicator left in place, and the next stage aligned.

The discriminator should be aligned next. For an output indicator a vacuum-tube voltmeter or an electronic voltmeter is best. However, a voltmeter with 10,000 to 20,000 ohms per

volt can be used. First the indicator should be connected across one of the diode-load resistors and the primary padder adjusted for maximum output. Then the indicator should be put across both load resistors and the secondary adjusted for zero output. This last adjustment is very sharp and considerable care should be taken to get it exactly correct. In some cases there may be three points where a zero output can be found. In those cases one point is when the circuit is completely out of resonance with the padding condenser too small. Another point will be when the padding condenser is too large. The third point, in between the first two, will be the correct setting. The correct setting can also be determined by the fact that the output rises rapidly on either side of the correct setting while it rises on only one side of either of the two other settings.

Alignment with an FM Oscillator and an Audio Output Meter.—Be sure that the oscillator that is being used has a frequency sweep at least as wide as the tuning curve of the set being aligned. The connections of the oscillator to the set are the same as in the previous case. The audio output meter is connected in the usual manner across the voice coil or from plate to ground of the output tube. The i-f circuits and both the primary and secondary of the discriminator are tuned for maximum output.

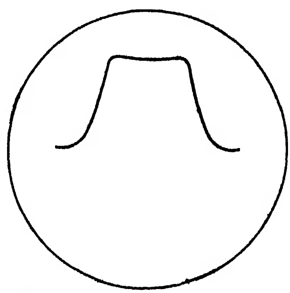


Fig. 240.—Pattern showing correct i-f alignment.

Visual Alignment.—To align the i-f amplifier the vertical plates of the oscilloscope are connected from the grid of the limiter to ground. The frequency-modulated oscillator is connected either from grid to ground of the mixer tube or on one stage at a time from grid to ground beginning at the tube ahead of the limiter. The secondary and primary padders beginning at the last are then adjusted to obtain a pattern similar to Fig. 240. The technique of obtaining this curve is the same as for an amplitude-modulated set.

To align the discriminator, the oscilloscope is connected across both diode-load resistors and the oscillator from grid to ground of the first tube ahead of the limiter. A pattern similar to Fig. 241 should be obtained. Adjust the primary padder to get the curve as tall and as straight as possible. The secondary

padder should be adjusted to get the crossover exactly at the center of the straight portions of the trace.

Contrary to the procedure with AM sets, the signal used when aligning an FM set should be large enough to allow the limiter to work normally. If the grid of the limiter is not drawing current when its transformer is aligned, the alignment will not be correct because the grid current will put a load on the transformer and will change the resonant frequency.

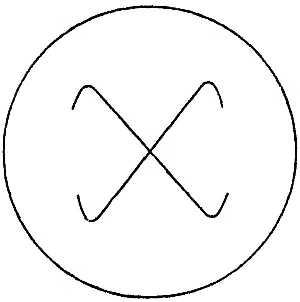


FIG. 241.- Pattern showing correct discriminator alignment.

Replacing I-F Transformers and Coils.[1]—Unquestionably it is cheaper and easier to replace a defective i-f transformer with an exact duplicate, provided, of course, the duplicate can be obtained. Even in normal times exact replacements are sometimes impossible to obtain; for example, i-f transformers much smaller than normal, transformers from a custom-built set with chrome or nickel shields, transformers with special mounting methods, or having other parts fastened to the shield, or a transformer having special circuits such as a third winding. When exact replacements cannot be obtained, then the extra labor of installing and adjusting an individual coil or set of coils is justified.

Types of I-F Replacement Transformers.—On sets having a single i-f tube it is necessary to have high-gain input and output transformers. When two or more i-f tubes are used, high gain is not necessary or even desirable for it very probably will cause oscillation. In these sets a low-gain transformer sometimes called an "interstage" transformer is used. These transformers add to the selectivity of the i-f amplifier without increasing the gain beyond the oscillating point. The output transformers are usually practically the same regardless of the number of i-f stages.

Notes on Removing and Replacing I-F Transformers and Coils.—Before removing an i-f transformer an accurate record should be made of the connections. Unfortunately the color codes

[1] This section is taken from material supplied by the Meissner Manufacturing Co. and is used with their permission.

of all i-f transformers are not standard and cannot be relied upon. One method of marking consists of two tags numbered alike, placed one on the wire left on the transformer and the other on the wire left in the set. It is essential to use tags with a cord that will not easily pull off. Just putting the wire through a tear in a scrap of paper is not satisfactory for it will not stay in place. Another method is to make a written record of the color code of wire in the transformer and in the set wiring. The colors often do not match. This record is necessary for the proper installation of the new transformer and particularly so if it is found necessary to repair the old transformer by replacing a coil.

The setting of the trimmer condensers should not be disturbed. This is particularly important if it is found necessary to replace a coil. It is a good plan to make a written memorandum of the number of turns, accurate to one-eighth of a turn, required to run the condenser to maximum capacity.

For transformers of recent manufacture the wiring should have the Radio Manufacturers Association code as follows:

Blue	Plate
Red	+B
Green	Grid
Black	a.v.c. or grid

For i-f output transformers feeding into one or more diodes the primary is the same as above. The secondary has the following code:

Green	Diode or diodes
Black	Load resistors for single diode
Yellow	Center tap for load resistor with two diodes

The blue and green leads are the ones that are most likely to cause oscillation if misplaced. They should be separated as far as possible from each other and should also be as short as possible. The black or yellow leads on output transformers should be as short as possible and kept as near the chassis as possible. The use of shielded leads, especially grid and diode leads, should be avoided. These leads add to the trimmer capacity and may detune the coil to such an extent that the trimmer cannot be reduced enough to bring the circuit back in resonance. In other cases the trimmer will have to be loosened

so much that it will not hold its adjustment. Usually the insulation in shielded leads is none too good. This causes changes in the capacity and losses with weather conditions and also reduces the Q of the coil.

If it is found desirable or necessary to replace a coil, the following additional points should be noted:

The transformer should be inspected to determine which trimmer is across the primary and which across the secondary. In some cases the two trimmers will be identical and in other cases they may have a different number of leaves and therefore a different capacity. If this is so, they should be reconnected properly. The trimmers should be properly marked or tagged.

The direction of the winding of each coil should be noted. Most transformers have both coils wound in the same direction. However, some have the coils wound in opposite directions.

Note to which end—inside or outside—of the primary the plate is connected and also which end of the secondary is connected to the grid or diode.

Measure as closely as possible the distance from each coil to the end of the dowel and the distance between coils.

The defective coil can then be removed and replaced with one as near like it as possible. It is important that the direction of the winding and the spacing of the coils be the same as the original. For the first test the coils should be temporarily fastened in place and the leads connected to the trimmers. The transformer should then be connected in the circuit and aligned. A check should then be made for sensitivity and selectivity. A lack of sensitivity—low volume—would indicate too loose coupling and the coils should be moved closer together. A lack of selectivity would indicate too tight coupling and the coils should be separated. The latter might also be indicated by getting the same station at two dial settings close together. Equipment for visual alignment is very convenient for use in checking the coupling of the coils. Remember that it is possible to have an excess of sensitivity which will cause oscillation.

If the padder has to be loosened up almost to its limit to align the transformer or if unloosening the padder to the limit brings it more nearly in alignment, the coil inductance is probably too high. This can be reduced by removing turns. About 20 or 25 turns should be removed and the transformer reassembled

and an attempt made to realign it. This procedure should be repeated until the padder is close to its original setting.

When the sensitivity and selectivity are satisfactory, the coils should be waterproofed by dipping in a good grade of radio coil wax.

Oscillation.—If the replacement transformer gives higher gain than the original, it may cause oscillation. If this is not too violent, it can be stopped by increasing the *C* bias or decreasing the screen-grid voltage. Note, however, that if the *C* is increased very much, it will seriously interfere with the operation of the a.v.c. circuit.

This feedback or oscillation can also be caused by coupling between the grid and plate leads. These should be placed as far apart as possible and kept away from the chassis.

If a glass tube is used, a close-fitting shield may stop the trouble. Often a change of tubes will stop oscillation.

Adjusting Push-button Tuners.—There are three types of push-button tuning systems: mechanical, circuit-switching, and motor- or solenoid-operated.

Mechanically Operated Systems.—Figure 242 shows one type of mechanically operated tuner. The plate *D* is a rocker that is connected to the tuning condensers through gearing. As the condenser rotates, the rocker assumes a more vertical position. The five vertical rods surrounded by coil springs behind the rocker are guideposts for angle plates whose angular position is determined by the setting of the screws *B*. These plates are concealed behind the frame *C*. When a button is depressed, the angle plate is pushed against the rocker and forces it to assume the same angle. This turns the condenser to the proper position for the station.

To set the buttons the station desired is tuned in with the dial knob. The button is then pulled off exposing the head of screw *B*, which is then adjusted until the angle plate is at the same angle as the rocker.

Some of the smaller sets have a lever-type mechanism. When the button is depressed, a roller on the other end of the lever bears against a heart-shaped cam on a shaft connected to the condenser shaft. The pressure causes the cam to rotate until the roller is in the depression in the cam. To set these buttons, loosen the locking device on the camshaft, press the desired

button, and then tune in the station. Repeat this for each button and then tighten the locking device.

Circuit-switching Systems.—Circuit-switching systems may govern the tuning either by changing the condensers in the circuit or by connecting various inductances across the tuning condenser. The inductance type usually known as "permeability tuning" is the more stable of the two methods. Trimmer switching is

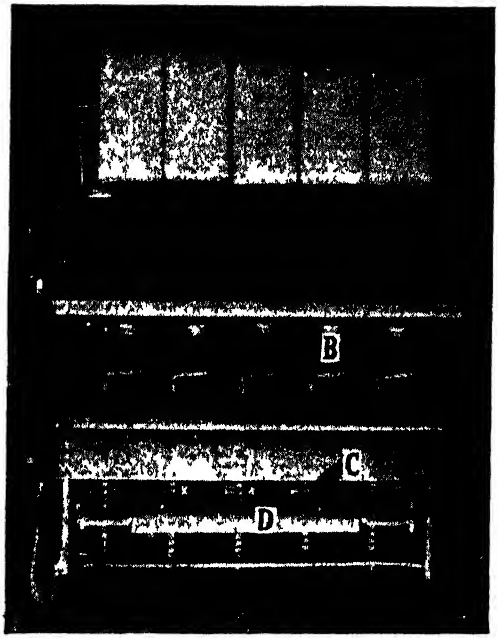


FIG. 242.—A mechanically operated push-button tuner.

used on the less expensive t.r.f. sets. A combination of the two methods with trimmer switching for the r-f circuits and permeability tuning for the oscillator is often used in superheterodyne sets. The circuit shown in Fig. 243 is an example of this combination. The tuning range of both the coils and the condensers is limited but they vary in size so that any station on the broadcast band can be tuned in on at least one button. The procedure for setting up these buttons is as follows:

1. Make a list of the stations desired, putting them in the order of their frequencies.

2. Depress the first button and adjust the core of the coil until the station is heard. Then adjust the r-f padder for maximum output.

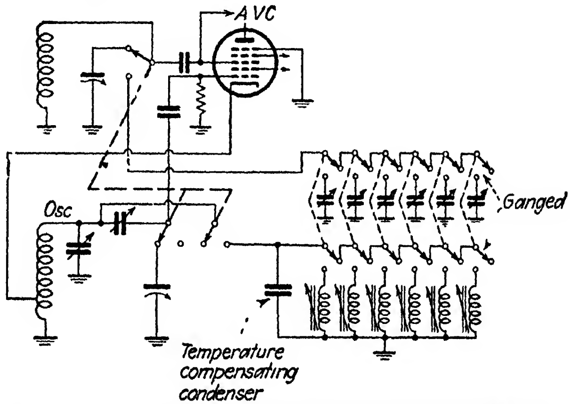


FIG. 243.—The schematic diagram of the GE HJ-1205, showing both trimmer and permeability tuning

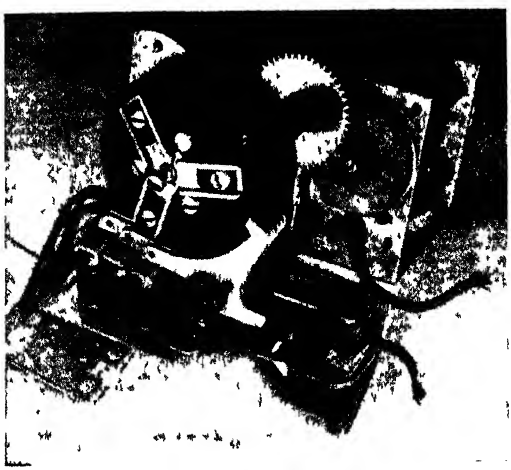


FIG. 244.—A motor-tuning unit

The oscillator is tuned first because it is necessary that the oscillator frequency be correct to receive the station even weakly and the r-f circuits are broad enough to allow some of the signal to get through even if they are not properly aligned.

3. Proceed with the remaining buttons in the same manner

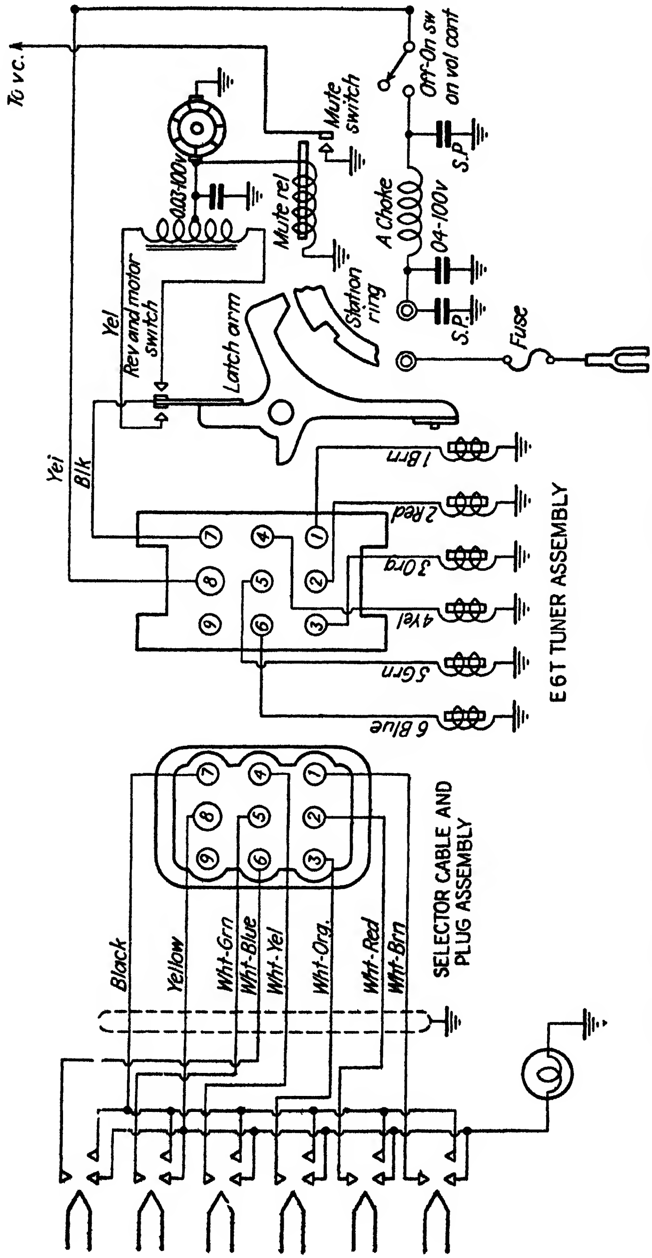


FIG. 245.—Schematic diagram of Motorola motor tuning system. (Courtesy of Galvin Mfg. Co.)

Motor-driven Systems.—The motor-tuning system used by Motorola is shown in Fig. 244. A schematic diagram of this system is shown in Fig. 245.

When a push button is pressed, the first two contacts energize an electromagnet, which attracts the latch arm and causes it to bear against the station ring which is on the same shaft as the tuning condenser. If the position of the tuning condenser is such that the latch arm rests on the higher portion of the ring, the upper contact of the motor is connected. If the condenser

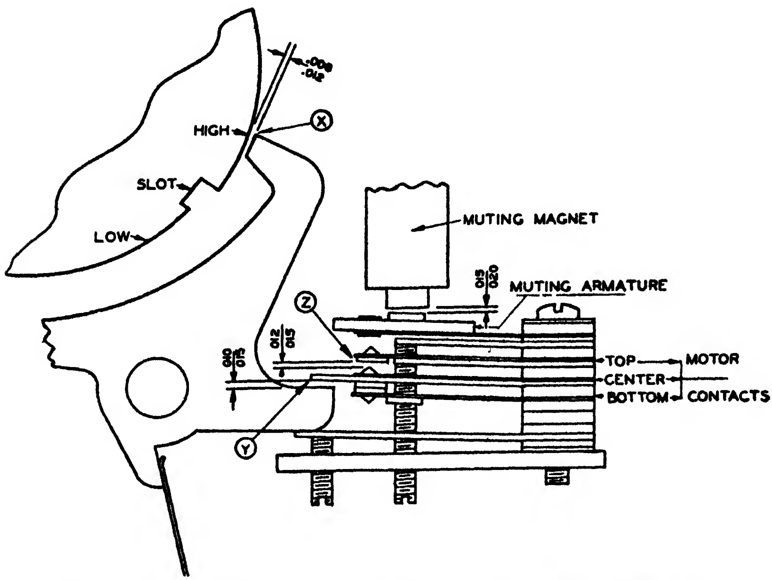


FIG. 246.—Detail of Motorola motor switch. (*Courtesy of Galvin Mfg. Co.*)

should have to turn the other way to reach the station, then the latch arm would rest on the lower portion of the station ring and the lower motor contact would be completed. The two contacts cause the current to flow through the field in opposite directions and so cause the motor to run in opposite directions. When the push button is pushed all the way in, the motor circuit is completed. Figure 246 shows the motor switch in more detail. Three of the six electromagnets, the latch arms, and the motor switch can be seen in Fig. 244. The muting relay coil is missing in the figure. Its armature can be seen on top of the motor switch. The six station rings are hidden by the fiber

insulating disks on each side of them. They can be identified by the Y-shaped support with the screw that locks them in position at the center.

To set up these buttons the following procedure should be followed:[1]

Important.—You will note that the 9-contact plug on the end of the control head cable has one pin that is shorter than the others. For the "setting-up" procedure, this plug should be inserted in its receptacle on the receiver only halfway. This will cause all the magnet terminals to be connected but will not permit the tuning motor to run during the adjustment, since the short pin will not make contact, thereby holding the motor circuit open. The motor should not run at any time during the "setting-up" procedure.

1. From the set of call-letter tabs provided, detach the proper ones for the six stations. The station tabs should then be inserted in the space provided in the back of the station tuning buttons. Cover the tab with a small rectangular piece of celluloid. Both tabs and celluloids snap into position.
2. Loosen the *automatic locking screw.* This screw should be turned counterclockwise four or five revolutions—far enough to assure plenty of looseness.
3. Turn the dial all the way to the l-f end (535 kc.).
4. Press the first button and hold it down. A faint click should be heard, indicating that the tuning magnet has attracted the latch bar.
5. Holding the magnet energized, turn the dial manually all the way to the h-f end (1,550 kc.) and then all the way back to the l-f end (535 kc.).
6. Still pressing on the button, tune in the station to be set on that button.
7. Proceed to set the remaining five stations. For each station follow steps 3, 4, 5, and 6, as outlined. *At no time in the setting-up procedure should the tuning motor be permitted to run.*
8. Tighten the automatic locking screw very securely. Do not hold the tuning knob while locking the automatic, but allow the mechanism to turn to its natural stop.
9. Push the plug all the way into the receptacle on the receiver housing so the short motor pin will also make contact.

[1] Courtesy of the Galvin Manufacturing Co.

A-C D-C Battery Portables.—Many of the a-c d-c battery portables have the filament connections as shown in Fig. 247 for operation on a-c d-c. In some cases *C* is a 15-volt 100-mf. condenser. In other cases it is a 150-volt 100-mf. condenser. In the first case, if a tube burns out, the *IR* drop in the resistor *R* is gone owing to lack of current and the line voltage is applied to the condenser causing it to fail. In the second case, the voltage rating of the condenser prevents failure so the condenser charges up to about 150 volts. When a new tube is put in the socket to replace the burned-out one, the condenser discharges through the tubes and since the capacity of the condenser is large the discharge current will burn out at least one of the tubes and may burn them all out. For this reason, when tubes in these sets are being replaced, the circuit should be checked to see if there is a condenser across the tubes. If so, a momentary short should be put across it to remove the charge before the tubes are put in the sockets. Do not attempt to discharge the condenser by shorting the filament prongs of the socket without a tube, for to do this would allow the condenser to discharge through the rest of the tubes and burn at least one of them out.

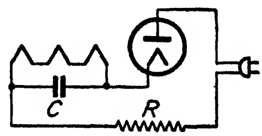


FIG. 247.—Filament circuit of an a-c d-c battery radio.

Another problem comes in the battery sets using the 1.4-volt tubes drawing 50- or 60-ma. filament current. When these tubes are used with series filaments, the plate and screen current of the power tube flows through the filaments of all the other tubes. With tubes having higher filament current this would be of no consequence but with these tubes the extra current may be a 10 per cent or more overload. This will materially shorten the life of the tubes. This difficulty is overcome by by-passing the filaments with a resistor to carry the extra current. The method of determining the size of these resistors is the same as for by-passing resistors used across pilot lights, as discussed in Chap. I.

Automatic-frequency-control Adjustments.—Before any attempt is made to adjust the a.f.c. circuits, it is absolutely essential that the rest of the receiver be in perfect alignment.

There are two adjustments to be made in the a.f.c. circuits, *i.e.*, the padding condensers in the primary and in the secondary

of the input transformer ahead of the discriminator tube. There are several ways of adjusting the primary padding condenser depending on the circuit used. When the a.v.c. voltage is obtained from the discriminator circuit, the primary padding condenser should be adjusted to obtain a minimum reading on an output meter connected in the normal manner when a fairly strong modulated i-f signal from an oscillator is applied to the grid of the first detector.

When the audio signal is obtained from the discriminator circuit, a modulated oscillator tuned to the correct intermediate frequency should be connected to the grid of the tube preceding the discriminator transformer. The primary padding condenser should then be adjusted for a maximum reading on the output meter. The accuracy of the setting of the secondary padding condenser is much more important than that of the primary. A practical and accurate method of obtaining this adjustment is as follows: Turn off the a.f.c. switch, and then tune in a local station, as accurately as possible, near the center of the dial. Now, without disturbing the setting of the receiver, connect an unmodulated test oscillator to the grid of the tube feeding the discriminator transformer. The coupling should be very loose. Use a 50-mmf. condenser, or, if the grid cap is insulated, put the oscillator clip on the insulation. The oscillator should be tuned exactly to the receiver intermediate frequency. Increase the output of the oscillator until a whistle is heard in the speaker. This will be a beat note between the oscillator and the station. Next tune the receiver until a zero beat is heard. Then turn on the a.f.c. switch and adjust the secondary padder until the zero beat note is again obtained. As a final check, the zero beat note should be obtained with the switch either on or off.

The secondary padding condenser can be adjusted also by the following method: With the a.f.c. switch off, tune in a local station of medium power or more. Connect a microammeter with a fairly low scale across both load resistors, *i.e.*, from the control voltage line to ground. When the a.f.c. switch is turned on, the secondary padding condenser should be adjusted for a zero reading on the meter. A vacuum-tube voltmeter can be substituted for the microammeter.

Since the plate current of the control tube is controlled by the a.f.c. voltage, it gives us a measure of this voltage. To take

advantage of this, a low-reading milliammeter should be placed in the cathode circuit of the control tube. Note the reading with the a.f.c. switch off. Then connect an unmodulated test oscillator to the tube feeding the discriminator transformer. Turn the a.f.c. switch on, and increase the output of the test oscillator until the reading on the milliammeter changes. The primary padding condenser should then be adjusted to obtain the greatest change in the reading originally obtained. The secondary padding condenser is then adjusted so that the reading does not change as the a.f.c. switch is turned on and off. This last adjustment is the most important one and should be made with considerable care.

The action of the a.f.c. circuits can be checked by mistuning a station with the a.f.c. switch off and seeing whether or not the station comes in undistorted when the a.f.c. switch is turned on. With the a.f.c. switch on, a local station should come in without distortion when the dial is turned about 10 kc. each side of the station's normal location.

Adjustment of Audio Filters.—In many of the better sets and in all of the high-fidelity receivers, the simple plate by-pass condenser connected from the plate to the cathode to by-pass the radio frequencies and keep them out of the audio amplifier is replaced by a low-pass filter. This has a much sharper cut-off. This is the technical way of expressing the fact that the filter will allow all frequencies up to a certain frequency known as the "cut-off frequency" to pass through quite easily but will offer considerable opposition to the passage of any higher frequencies. This is its main advantage over the simple condenser, which gradually increases its opposition as the frequency is lowered. The circuit of a low-pass filter is shown in Fig. 248. These filters are adjusted to pass the highest audio frequency that the receiver is designed to reproduce. It may be as low as 6,000 or 7,000 cycles, or it may be as high as 12,000 cycles. It frequently is 10,000 cycles. It is adjusted by feeding the highest frequency that the receiver is designed to reproduce into the grid of the tube having the filter in its plate circuit and then

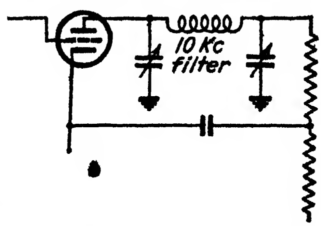


FIG. 248.—Audio-frequency filter.

adjusting the filter for minimum output as read on an output meter. If an a-f oscillator is not available, the proper note can be obtained by tuning the receiver to a station and then connecting a test oscillator to the antenna connection and tuning the oscillator to zero beat. The oscillator dial should then be shifted the proper amount to give the desired note. If it was 10,000 cycles, the required amount would be 10 kc., or 10,000 cycles. Odd values such as 6,000 or 12,000 can be estimated accurately enough for this purpose.

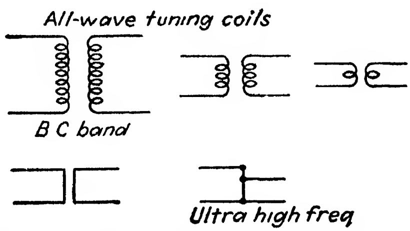


Fig. 249. —All-wave tuning coils

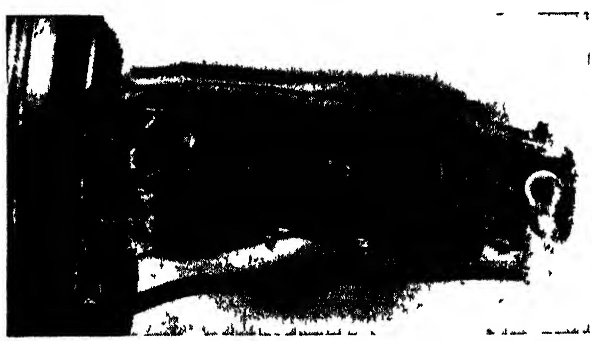


Fig. 250.—Long-wave "X" band coils

Short-wave and All-wave Receivers.—On the broadcast band the oscillator frequency is always above the incoming signal frequency. However, in the h-f bands, and especially in the very high frequency bands, the oscillator frequency is often below the incoming signal frequency. This change is made because the stability of the oscillator decreases as the frequency is increased. In some of the larger all-wave superheterodynes, two separate oscillators are used in two different oscillator circuits to maintain greater stability in the oscillator.

At the higher frequencies, it is more difficult to keep the incoming signal frequency from causing the oscillator to deviate from its prescribed frequency because of the increased coupling of the circuits. This increase in the coupling is caused by the reduced reactance of the capacitance between tube element and other

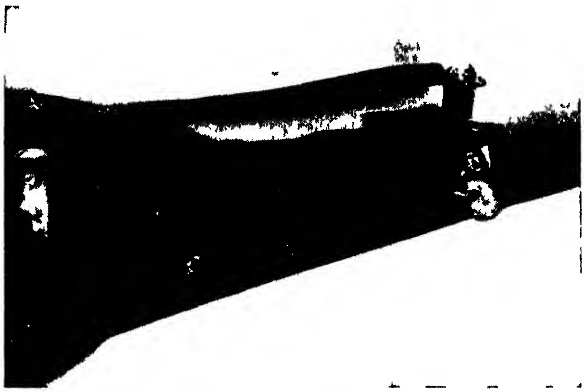


FIG. 251.—Broadcast coils.

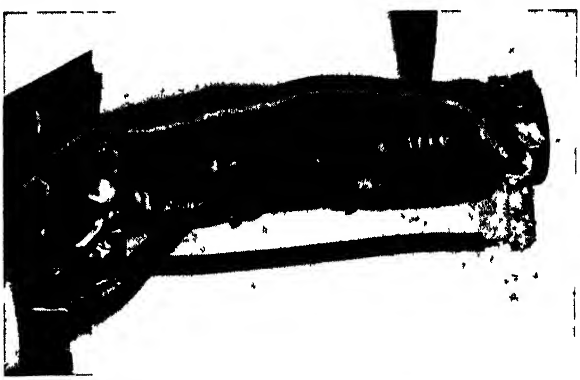


FIG. 252.—Short-wave coils.

circuit parts. For this reason, it is impossible to use the converters of the 6A7 type on the extremely high frequencies because the capacity between the oscillator and the detector grids is too high. To overcome this difficulty the 6L7 type, which uses a separate oscillator tube, was designed.

All-wave Tuning Coils.—Figure 249 shows the variation in the tuning coils of a set as the frequency increases. For the extremely

high frequencies, the whole transformer, both primary and secondary, may consist of a short piece of bus bar, as shown in the last diagram.

The position of the wiring in the h-f circuits is very critical. The slightest change in the position of the wiring will easily affect the alignment of the set to such an extent that the padders cannot bring the circuits into resonance. This point must be kept in mind when this type of set is being serviced. The last thing that should be done when working on an all-wave receiver is to check the alignment on all of the bands.

Dead Spots on the Tuning Dial.—Dead spots on the tuning dial can be caused by the tuning-condenser plates touching at certain spots. This might be caused by loose bearings, which usually can be adjusted to remove the difficulty. If the condenser has a die-cast metal frame that has warped, very little can be done except to replace the condenser. This type of trouble is always accompanied by crackling and popping as the dead spot is approached.

A very frequent cause of dead spots on the dial of a superheterodyne is the failure of the oscillator to oscillate over the entire band. A very good test to determine whether or not the oscillator is oscillating consists in inserting a milliammeter in the plate circuit and then shorting the oscillator tuning condenser, or doing anything else that will positively stop any oscillation. If the oscillator was originally oscillating, there will be a change in the plate current when it stops. Sometimes it will be an increase and sometimes it will be a decrease, but in any case a change in the plate current indicates that the oscillator was oscillating. Try replacing the oscillator tube. The author has tried as many as eight tubes in some cases before one was found that worked satisfactorily over the entire band. This is especially true when a pentode-type tube is used as a detector modulator. If the oscillator bias is obtained by the use of a *C* bias resistor, try reducing the value of it slightly. This will increase the strength of the oscillation, but if it is increased too much a hissing sound will be heard when the receiver is tuned to the portions of the dial where the oscillator worked originally. Best results are usually obtained with a bias resistor of about 10,000 ohms.

It is possible that the oscillator voltage may be so high (or the first detector grid bias so low) that it will drive the control grid of the first detector positive. This usually occurs at the high frequency end of the band, where in most cases the oscillator develops its maximum voltage When the first detector control grid is driven positive, grid current flows in the grid circuit and the sensitivity of the r-f stage as well as that of the first detector is seriously reduced. If this condition is suspected it can be easily checked by connecting a 0–1 milliammeter in series with the first detector grid coil (between the low potential end of the coil and ground) and rotating the tuning condenser through its entire tuning range. If at any time the meter needle moves, the first detector bias should be increased or the oscillator voltage reduced. The oscillator voltage may be reduced by reducing the coupling between first detector and oscillator coils, or by reducing the coupling between the two oscillator coils, or by reducing the plate voltage of the oscillator, or by reducing the grid leak or condenser—or both—of the oscillator.[1]

In many receivers, a fixed resistor is connected in series with the oscillator grid, as shown in Fig. 217, to maintain at a more constant level the voltage developed by the oscillator.

A vacuum tube voltmeter may be used to measure the value of the oscillator voltage induced in the control-grid circuit of the first detector. If the vacuum tube voltmeter is calibrated in R. M. S. volts, the oscillator voltage measured must be multiplied by 1.4 to find the peak voltage. This peak voltage should never equal the bias voltage of the first detector.[1]

If it is suspected or known that the oscillator is not working properly, it is possible to substitute a test oscillator for it by connecting the test oscillator between ground and the plate or grid of the oscillator tube or to the lead that feeds the oscillator output into the first detector. Care must be used to see that any d-c voltages are blocked out of the test oscillator by a condenser.

This type of trouble usually occurs at the l-f end of the dial, and it is sometimes necessary to turn the dial nearly to the other end before the oscillator will start again. There usually is no noise in the speaker as the oscillator stops.

Intermittent Operation.—Intermittent operation is one of the most difficult problems encountered by the serviceman. There are so many causes for this trouble that it would be impossible

[1] *Sylvania News*, Vol. VII, No. I, May–June, 1937.

to list them all; however, some of the more common ones will be mentioned. After eliminating any doubtful tubes and checking the voltages, look for one of the following:

Intermittent operation has been caused by such unlooked-for things as a piece of BX in the basement which made contact with a water pipe when anyone stood on a certain spot on the floor above. The ground wire that ran near by was electrically changed by this contact and caused the trouble. This difficulty is sometimes caused when a certain light or appliance is turned on or off. Practically every case of this kind can be traced to the use of an inefficient antenna and ground system. Usually, an inside antenna, or no antenna, or the antenna post grounded will be found. The installation of a modern noise-reducing antenna system and a real ground to a separate ground rod will stop this difficulty in nearly every case. The easiest way to determine if this is the source of the difficulty is to remove the chassis to the shop. If the set operates properly on the bench but not at home, the trouble is obviously in the antenna or building wiring.

Intermittent operation is also caused by:

1. Poor contact to the rotors of the condensers. The addition of a pigtail connection is often helpful. Other high-resistance joints in the tuned circuits.

2. Leaky by-pass condensers. For this test, a neon-bulb condenser tester or an ohmmeter reading at least up to five megohms is required.

3. Leaky blocking or coupling condensers used in resistance or impedance-coupled circuits. A condenser that is leaky to the slightest degree will cause trouble here.

4. Intermittently open resistances. Sometimes a resistance will open when warm or hot and will close when cold. The expansion due to the heat opens it. This is one of the reasons for one of the fundamental rules for testing any equipment, *viz.*, always test a piece of equipment with the same voltage and current that it carries when in use in the set. Condensers will show leakage on high voltage that would not be great enough to show at a lower voltage. The presence of gas in a tube may be overlooked if the tube is tested on low voltage.

5. Intermittently open heaters in tubes.

6. Poor connections in the antenna or ground circuit.

7. Swinging antenna that varies the tuning or grounds the antenna circuit.

8. Faulty antenna insulation.

For the type of intermittent operation in which reception can be restored by turning the power switch off and on again, look for an open or intermittently open grid circuit. The stoppage is caused by a grid blocking up. Turning the set off allows the charge on the grid to leak off so the set operates again when it is turned on.

Until the introduction of the signal-tracing method of servicing, there was no direct method of finding the source of intermittent operation. There were two methods used to hasten the permanent breakdown of the intermittent part. Heat was applied by means of an electric heater or some other method with the hope that the defective part would break down completely before too many good parts suffered. Much care had to be used to prevent damage to condensers and transformers by melting the sealing compound in them. Another method that had the same drawbacks was to apply excessive voltage to the set and hope that the weak part would permanently fail so that it could be located. Here again many good parts could be damaged before the defective part was found.

Signal-tracing Method of Servicing.—For tracing down the source of intermittent operation, the multichannel Analysts and Chanalysts are far superior to any other test equipment that ever has been designed. One of the difficulties found in locating intermittents is that, after waiting possibly hours for the set to show signs of difficulty, the mere touching of a test prod on a circuit may cause the set to operate normally again. Then another waiting period is necessary. By connecting the vacuum-tube voltmeter section across the antenna-ground connections of the set any variation in the input can be detected. If the r-f section is connected across the oscillator, any variation in its output can be noted. The operation of the audio section can be observed by connecting the audio section of the analyzer to it. Power-supply difficulties can be located usually by the "watts input" indicator. With the output indicators set, other service work can be done until the set shows signs of difficulty and then a glance at the output indicators will indicate in which circuit the disturbance occurred. For example, if only the audio

indicator revealed a change, the trouble must be between the point where that probe was connected and the one ahead of it. The r-f probe, which usually is also the i-f, could then be moved to the input of the second detector. This test will definitely determine whether the trouble is in the i-f amplifier, in the second detector, or in the audio amplifier. The proper probes can then be moved closer together until the portion of the circuit between them is very small and only a very few parts could be the cause of the difficulty. Usually, all these parts can be replaced at less expense than the time spent trying to find the single defective part. In interpreting the indications of the output indicators it should be realized that, if the signal at any point is changed, all the indicators beyond that point will indicate a change also. For instance, if the oscillator output decreased, indicators in the i-f and audio amplifiers also would indicate a decrease in the signal.

Fading.—Fading differs from intermittent operation in that the signal fades out gradually instead of breaking off abruptly. The causes and cure for fading, other than the type of fading discussed in Chap. II, are the same as for intermittent operation.

Adjusting Sets to Get Police Calls.—Usually an attempt to change the tuning range of a receiver will prove unsatisfactory. In some cases, when the stations on 550 kc. do not come at the extreme end of the dial, a few turns may be removed from the tuning coils, which will enable the set to tune to the police calls at the h-f end of the dial. Another possible method of receiving the calls is to put fixed condensers of about the same capacity in series with the tuning condensers and then shunt each of the fixed condensers with one section of a ganged switch. This switch is arranged to short out the fixed condensers for reception of the regular broadcast band. The difficulty with this scheme lies in the leads to the switch. These will necessitate realigning the stages, which is not very serious, but the leads from the various stages coming together at the switch do present a big opportunity for feedback, which may be very difficult to overcome.

Volume Controls.—Many of the volume controls are of carbon composition and, therefore, they may be expected to behave like the carbon resistors in regard to change of resistance due to age, heat, and moisture. Many cases have been found in which the sensitivity of the receiver was very low owing to a change in

the resistance of the volume control. For the same reason, it is important to replace a volume control with one having the proper resistance value as well as the proper taper, or graduation, of the resistance. If the wrong taper is used, much of the rotation of the control will have very little effect on the volume and the usable portion is all crowded into a small portion of the rotation.

Many of the volume controls are a part of a voltage divider network, which also furnishes the screen grid or other voltages. The use of a volume control having the wrong resistance will alter the voltages at these points and may cause serious distortion.

No attempt should be made to repair a volume control by rubbing lead-pencil graphite on it, for this always results in a wrong resistance value and improper taper, both of which make an unsatisfactory repair.

Automatic Volume Control.—Since a.v.c. will not be successful unless variable-mu tubes are used, the addition of this feature to older sets requires the changing of the tubes. This usually means a mismatch between the tubes and the transformers, and will result in inferior performance. Oscillation and difficulty in tuning often result from the change.

Servicing Automatic-volume-control Circuits.—By far the most frequent difficulty with a.v.c. circuits is with the tubes. Since there is a very low d-c voltage on this circuit, there should be very little difficulty with burned-out condensers and resistors. An open filter resistor or a shorted filter condenser would prevent the control voltage from getting to the tubes, and no a.v.c. action would take place. A shorted resistor or an open condenser would allow the r-f or i-f voltage across the diode load resistor to be fed back into the amplifier, thus causing oscillation. If the value of any of the resistors changes materially, it will change the time constant of the circuit and will not only cause the volume to follow the modulation of the signal if the resistance is lowered but will also make the a.v.c. action sluggish if the resistance is increased. Any of these conditions can be easily detected by the use of an ohmmeter.

Low a.v.c. voltages at the grids of the tubes are sometimes caused by leaking insulation at the tube sockets or in the wiring near them. This allows current to flow from the diode-load resistor through the filter resistors to the leak. The *IR* drop in the resistors causes the loss of a.v.c. voltage. Look for poorly

insulated wiring and for dirt and rosin on the tube sockets. Burned insulation on the wiring caused by contact with the side of a soldering iron is often the cause of such leakage.

The operation of the a.v.c. action can be observed by putting a milliameter in the plate or cathode circuit of one of the controlled tubes and tuning in the strongest local station. The a.v.c. action can also be observed by putting a vacuum-tube voltmeter across the grid-cathode circuit of one of the controlled tubes. This connection, however, has a slight detuning effect on the stage, owing to the input capacity of the meter. The a.v.c. voltage can also be read by placing the vacuum-tube voltmeter across the diode-load resistor; however, this does not check the voltage actually put on the grids of the controlled tubes. A microammeter can also be placed in series with the load resistor and the voltage across the resistor computed from Ohm's law. As the receiver approaches resonance with the station, the plate current of the controlled tubes should decrease until resonance is reached. If it stops decreasing before resonance is reached, it indicates that the a.v.c. voltage is limited. This might be caused by low emission from the cathode to the diode plates, or it might be due to the load resistor being too low resistance. If a test oscillator is used to replace the local station, care must be taken to see that the signal is not excessive, for the oscillator can put out a signal so large that no a.v.c. can control it.

Tuning Indicators.—The a.v.c. action on a set keeps the volume nearly constant over a rather wide range on the dial and makes it very difficult to tune the set accurately by ear. To remove this difficulty and to ensure more accurate tuning, various tuning indicators have been introduced.

The a.v.c. action causes the grid bias on the controlled tubes to rise as the signal strength increases and to fall when the signal becomes weaker. But increasing the grid bias on any tube will decrease the plate current, and decreasing the bias will increase the plate current. If a milliammeter is put in the common plate lead of the controlled tubes or in the plate lead of a single tube, a minimum reading on the meter will indicate exact resonance. Insofar as most people are accustomed to expect maximum results when the pointer of any meter moves to the right, this

action is obtained by turning the meter upside down from the ordinary position.

Shadowgraph.—The operation of the shadowgraph tuning indicator is the same as that of the meter already described. The only difference lies in the construction of the meter. This meter has, in place of a pointer, a small vane mounted on the movement in such a way that it intercepts the light from a pilot lamp. The shadow of the vane is cast on a screen exposed near the tuning dial. When the signal is exactly tuned in, the plate current will be a minimum and the vane will be turned so that its edge is toward the light and a minimum shadow is cast on the screen. When no signal is tuned in or the signal is not accurately tuned in, the shadow will always be wider than the minimum amount.

Servicing Magic-eye Tuning Indicators.—A lack of brilliance in the illuminated portion of the eye, *i.e.*, a lack of contrast between the light portions of the eye and the shadow, usually is caused by a defective tube having low cathode emission or by low heater voltage.

If the eye closes completely or the light portion overlaps, it is an indication that too much voltage is being applied to the control grid. This may be caused by too high a.v.c. voltage or a faulty voltage-divider network supplying the grid excitation. This effect will also be caused by excessive resistance in the resistor between the target and the plate of the indicator tube.

Hum.—Hum might be caused by any of the following conditions:

1. Open filter condenser in the power supply.
2. Shorted resistors or open condensers in a resistance-capacity filter.
3. Open or uncentered center-tapped resistor across the heater circuit.
4. Loose or missing shields.
5. Old electrolytic condensers having high leakage. This lessens their filtering ability and also increases the current through the chokes, which lowers their inductance and their filtering ability.
6. Low voltage in the power line.
7. Grounded audio-transformer windings.
8. Shorted filter choke in power supply.

9. Half of the power-transformer secondary open.

10. A hum that occurs only when the set is tuned to a certain spot on the dial is often caused by pickup from the power line. This difficulty can be remedied by using a good line filter in the power-supply cord. This type of hum can also be caused by a-c leads such as heater leads being too close to the grid and plate leads. Under these conditions, the a-c flux will generate a voltage in the grid or plate leads that will modulate the r-f or i-f current in the leads.

11. Any trace of hum left in the oscillator plate supply will modulate the oscillator output, which in turn will modulate the i-f output of the first detector. This again is "tunable hum." The remedy is obviously more filtering in the oscillator-plate supply lead.

12. Unbalanced plate currents in push-pull stages.

13. If the capacity of the two condensers used in series in a voltage doubler circuit is not the same, a hum will result.

14. Unequal emission from the plates of a full-wave rectifier.

15. In a-c d-c sets with −B isolated from chassis hum may be caused by capacity between the diode leads and the chassis. The capacity may be due to having the wires too close to the chassis or by using shielded leads.

Resistance-capacity filters in the plate and grid circuits reduce the hum that is not entirely removed by the power-supply filter. However, it has been found that reducing the effectiveness of the filter in one stage sometimes reduces the over-all hum, because the additional hum introduced in one stage balances out the hum in the next stage rather than adding to it.

As a rule resistance-capacity filters in the grid circuit of resistance-coupled audio amplifiers will increase the hum rather than decrease it.

Sometimes a hum will develop in an audio amplifier after it has been in use for some time. Some of the causes of hum of this type are as follows:

1. Hum frequently develops when tubes are practically worn out. This may be caused by heater-cathode leakage or by unbalanced push-pull tubes.

2. Open condensers in the power pack filter will cause a bad hum. This trouble has been discussed more fully in Chap. VII, "Power Supplies," page 165.

3. An open center-tapped resistance across the heater or filament leads will cause hum.

4. Many amplifiers have isolating resistances in series with the plate, screen-grid, or control-grid leads to prevent hum. If any of these resistances are shorted, a hum results.

5. Electrolytic condensers are frequently used in the filters in plate and grid circuits. These condensers lose their filtering ability by drying out. The quickest test for this difficulty is to put a good condenser in parallel with them.

Hum is usually caused by lack of filtering in the power supply. This can be quickly checked by putting an 8-mf. or larger condenser across the output of the supply. If the hum is gone or if it is materially reduced in volume, more filtering in the power supply is indicated. If this treatment has no effect on the hum, then the best method of attacking the problem is to determine which stage is generating the hum. This can be determined by shorting the input to the various stages, starting with the last. If the grid is at ground potential, it may be shorted by clipping a wire from the grid to the chassis. In many circuits, the grid is not at ground potential, and, in this case, the grid can be effectively grounded by clipping a 1- or 2-mf. condenser from grid to chassis or cathode. The short on any stage prevents any signal or hum from the preceding stages from going any farther, so that a stoppage of the hum indicates that the hum is coming from some stage ahead of the one shorted. The stage that does not stop the hum when it is shorted is the one in which the hum is being introduced. Usually the first stage will be found to be mainly responsible for the hum. This is due to the fact that it has the greatest amplification behind it, and, therefore, a very slight hum picked up in this stage will be amplified and be very annoying at the loud-speaker. If the first stage is found to be introducing the hum and an input transformer is used, try disconnecting the secondary from the volume control or the grid circuit. In almost every case, it will be found that hum voltages picked up by this transformer are responsible for the difficulty. The trouble may be corrected by not using the transformer or using one that has hum-bucking coils and heavy shield.

In some sets using permanent-magnet speakers the high voltage is fed into the output transformer at a tap so placed that

the hum voltages in the portion of the coil carrying the output-tube plate current are exactly balanced by the hum voltages in the portion of the coil carrying the plate and screen voltages for the remainder of the set. The circuit is shown in Fig. 253.

Hum in this circuit might be caused by a poor output tube, by the condenser *A* being too low capacity, by the resistor *B* having the wrong resistance, or by the resistor *C* being incorrect.

Noisy Reception.—This might be caused by:

1. Bad joints in the antenna or ground circuits.
2. Poorly insulated antenna.
3. High-resistance ground connection, *e.g.*, a long steam pipe, especially if there are other radios connected to the same steam system, as is the case in an apartment house.

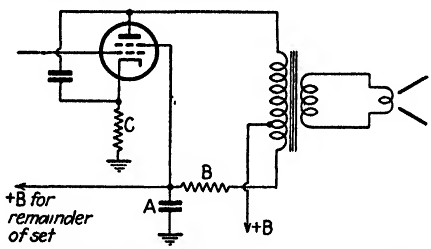


Fig. 253.—A schematic diagram of a hum-bucking circuit.

4. Partly open resistors. Resistors that have been overheated are very apt to cause noise.
5. Tuning condensers with the plates so close that dust partly shorts them and causes very small sparks when the signal builds up a voltage across the condenser.
6. Poor contact at the a-c plug or wires loose at the plug.
7. Loose lamp bulbs or fuses in the same building.
8. Leaky condensers.
9. Worn volume control.

See Chap. XI for the elimination of man-made static.

The quickest and most accurate method of locating noise is to short the grid circuits of the tubes one at a time beginning with the first and note which one cuts out the noise first. The stage ahead of that point is the source of the trouble. If shorting the antenna and ground eliminates the noise, look for trouble in the antenna ground system or in the house wiring.

Servicing High-fidelity Receivers.—High-fidelity receivers are subject to all the ills encountered in standard receivers and are

serviced in the same manner. However, the high-fidelity receivers have a few additional troubles all their own. But before these are discussed, a clear understanding of just what constitutes a high-fidelity receiver should be gained. The Radio Manufacturers Association defines a high-fidelity receiver as "one which has an audio reproduction range from 50 to 7500 cycles, with a harmonic distortion content not to exceed 5 per cent, and a volume range of reproduction of at least 70 db." The standard set usually has an audio reproduction range from 100 to 4,000 or 5,000 cycles and a volume range much smaller. The midget sets have both frequency and volume ranges very much more restricted than this.

The wide a-f band in the high-fidelity receivers causes many complications. In the first place, the broadcasting stations are only 10 kc. apart, which allows each an audio-band width of 5,000 cycles without interfering with the station on the adjacent channel. Likewise, if a receiver is designed to accept an audio band of 7,500 cycles, the higher frequencies of the stations on the adjacent channel will be heard, which produces a high-pitched twittering that the engineers have called "monkey chatter." This is sometimes accompanied by a whistle caused by the heterodyning of the carriers of the two stations. The only way to avoid this difficulty is to find a station with high-fidelity programs on a channel remote from any of the near-by stations. Because of this difficulty, all high-fidelity sets have incorporated in them some method of restricting the audio-band width at the option of the operator. There are several methods by which this can be accomplished. It really is a problem of selectivity, and since most of the selectivity of a superheterodyne is obtained in the intermediate amplifier the devices for controlling the selectivity are located there. Most of the devices vary the coupling between the primary and the secondary of the i-f amplifier transformers. Close coupling of the coils will give poor selectivity and high fidelity. Loose coupling will give good selectivity, but the high frequencies in the audio range will be cut off.

One method of varying the coupling uses fixed coils and a movable iron core. Partly removing the core will reduce the coupling and improve the selectivity. When the core is inserted in both of the coils, a maximum of coupling is obtained as well as

the highest fidelity that the set is capable of producing. In this method, both coils are fixed and pigtail connections are not required. Also a very small movement of the core will produce all the change in the fidelity and selectivity that is required. In a second method, the core and one of the coils are fixed, and the other coil is moved onto and off the end of the core. Very little movement is required here also, but, since it is a coil that is moving, pigtail connections are required and these are certain to require attention after a period of time. The third method uses air-core coils, one fixed and the other movable. In this case, considerably more movement is required to obtain the same results. This increases the difficulty with the pigtail connections. A fourth method of varying the coupling consists of shielding the primary from the secondary and coupling them through a variable condenser. The greater the capacity of this condenser, the closer will be the coupling. The selectivity of the amplifier can also be controlled by inserting a variable resistance in series with the secondary and its tuning condenser. High resistance gives high fidelity and poor selectivity. Reducing the value of the resistance will increase this selectivity.

High-fidelity sets are purposely made with low sensitivity because a set with high sensitivity would pick up a station on practically every channel and therefore there would not be a channel on which the set could be broadened out to receive high-fidelity programs without having interference from stations on adjacent channels.

Tone-compensated volume controls are usually used. These were discussed in Chap. IX. The power output of the high-fidelity receivers is usually higher than that of the standard receivers, because it takes more power to reproduce the lower notes in the range of the high-fidelity receiver and also to give the desired volume range. Some receivers use two or three speakers fed by a single amplifier through a filter network, which provides each speaker with its proper range of frequencies. In other sets, separate amplifiers are used for the high and low frequencies. In this case, the frequency filter system is between the detector and the first a-f amplifier tube.

Some of the later high-fidelity sets have some form of acoustical labyrinth built into the back, which prevents any radiation of the sound from the back of the speaker except that which comes

through the labyrinth. These are so designed that they reinforce the frequencies that are otherwise slighted and, therefore, increase the over-all fidelity. One manufacturer forms a sort of folded horn by enclosing the back of the cabinet and then installing a number of shelflike partitions as indicated in Fig. 254.

The number, the spacing, and the material of which the shelves are made were carefully chosen to subdue the frequencies that were overemphasized and to reinforce those that needed this assistance. Another manufacturer enclosed the back of the cabinet and then installed a number of tubes opening through the bottom of the cabinet. The size and the length of these tubes were chosen so that the sound coming out of them would be in the proper phase to reinforce frequencies that had been slighted otherwise and to buck frequencies that had been overamplified.

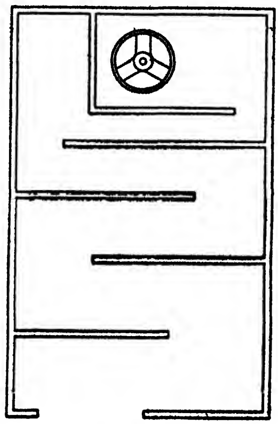


FIG. 254.—Diagram showing the arrangement of the interior of an acoustical labyrinth.

In a high-fidelity set everything that can be done is used to provide the highest quality of output. If any portion of the set slights any portion of the a-f band, then some other section is made to compensate for it. Thus the audio amplifier can be made to compensate for deficiencies in the r-f circuits and also for the characteristics of the speaker used. Because this is so, it is very important that any defective parts in high-fidelity sets be replaced by exact duplicates even if the values seem to be different from the usual practice.

When a high-fidelity receiver is installed, it should be tried in various parts of the room. In some cases, the sound will be much improved if the set is placed in the center of the short side of the room; in other cases placing the receiver across the corner of the room will give superior results. No definite rule can be laid down. Each installation will require experimentation to determine which is the best position. In all cases, try to have the listeners as nearly straight in front of the speakers as is possible. The quality of the reproduction at the sides of the cabinet is always inferior.

Servicing Inverse Feedback Circuits.—Lack of volume with good quality might be caused by too much feedback. This would happen if the resistor R_1 (Figs. 105 and 106) was too large or the resistor R_2 was too small.

Lack of volume with poor quality might be caused by the condenser C (Fig. 105) being leaky or shorted. If this happens, R_1 and R_2 will become excessively hot and may burn out.

Excessive volume with poor quality might be caused by insufficient or no feedback. This condition might be due to an open condenser C, or resistor R_1 (Figs. 105 and 106) might be too small or resistor R_2 too large.

An accessory for a cathode-ray oscilloscope (such as was used by the RCA engineers at a serviceman's meeting) for obtaining the frequency-versus-amplification curve of the amplifier would be most helpful in testing inverse feedback circuits and making adjustments to them. At present, no such equipment is commercially available.

Audio Howling.—An audio howl may be caused by a number of conditions. If the resistance-capacity filter in the a.v.c. line loses its effectiveness, a howl will result. Look for shorted resistors or open condensers in the filter. This howl will stop when the second detector tube is removed from the chassis. Open by-pass condensers across any of the tube elements, plate, screen, etc., will often cause howling. Unless the plates of the tuning condensers are very rigid and are securely fastened to the shaft and framework, the sound waves may set them to vibrating. This causes a small change in the tuning which will vary the input to the tubes in such a way that a howl results. The same result is occasionally found with the elements of a tube as the vibrating member. In a number of sets the tuning condenser gang is mounted on rubber to avoid this difficulty. After a period of time the rubber may harden or pack down, which allows the condenser frame to touch the chassis. If this happens, a howl is almost sure to be the result. This often starts as an intermittent howl, which becomes more frequent as time goes on.

Automatic Fidelity Control.—A variety of automatic fidelity control can be obtained by connecting the suppressor grid of a type 6D6 or 6K7 tube to the a.v.c. line. The tube so connected is usually the i-f tube just ahead of the second detector. This connection results in somewhat broader tuning on local stations

with increased fidelity and sharper selectivity with some attenuation of the higher frequencies on weak signals. This is desirable, for it reduces the static and tube hiss when distant stations are being received.

Damaged Audio Transformers.—No attempt should be made to use an audio transformer that has been overheated or one that has had an overload of current through the windings. These conditions change the magnetic properties of the core to such an extent that the characteristics of the transformer are no longer the same and may seriously affect the frequency characteristics of the amplifier.

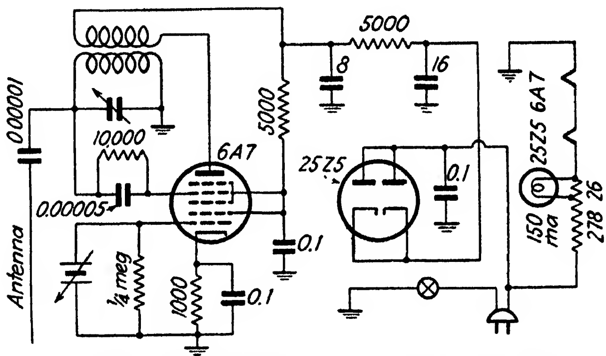


Fig. 255.—Circuit diagram of a phonograph oscillator.

Phonograph Oscillators.—If there is no phonograph jack or terminal board on a modern radio, it is quite certain that there is some technical reason for its omission and an attempt to add one would probably not succeed. There are at least two reasons why a phonograph cannot be fed into the audio amplifier of a radio set: (1) There may not be sufficient a-f gain to give reasonable volume. (2) The frequency characteristics of the amplifier may have been arranged to offset undesirable characteristics in the r-f or i-f portion of the set and these characteristics in the audio amplifier would result in poor tone quality from records.

Any radio can be used to reproduce phonograph records by the use of a phonograph oscillator. Most of the circuits are like the oscillator-modulator circuits in superheterodynes except that the r-f input is replaced by the pickup signal. In some cases the output is connected to the antenna-ground connections of the radio. In others it is fed into a short antenna built into

the power cord of the oscillator and feeds into the radio set through its power cord.

The power of these oscillators should be kept very low; otherwise they will be classified as an unlicensed broadcasting station by the Federal Radio Commission, which frequently assesses heavy penalties for such operation.

A typical circuit of a phonograph oscillator is shown in Fig. 255.

Most of the oscillators have a limited tuning range usually at or near one end of the broadcast band. To put an oscillator in operation the radio should be tuned to some spot at the proper end of the band where no radio program is received and then the oscillator should be tuned to the radio. If push-button tuning is used on the set, one of the buttons can be set up to receive the phonograph.

Servicing a phonograph oscillator is no different than the servicing of the oscillator in a superheterodyne. The same difficulties may keep it from oscillating and the same remedies will apply.

Servicing Phonograph Pickups.—The construction of most of the magnetic pickups is very similar to the mechanism of the balance-armature speaker unit. The permanent magnet loses its strength after a period of years. This results in weak signal output. The strength of the magnet can be tested by placing any steel tool against it and noting the force required to remove it. Distortion is sometimes caused by an accumulation of magnetic particles that collect in the armature air gap. These can be removed with a strip of stiff paper or a small brush with fairly stiff bristles. The most frequent cause of distortion and weak volume is the rubber damping around the armature. This varies somewhat in the various makes, but a simple inspection of it when the pickup is opened will show what is needed. The most difficult part of the repair of the packing is to find a sheet of rubber of the correct thickness and pliability. If possible, the proper packing should be obtained from the manufacturer. If this is impossible, a wide rubber band may be of the proper thickness. In some cases, a piece of automobile inner tube can be used; however, these are usually too thick. If the packing is too thin, distortion will result; if it is too thick, it will usually be impossible to assemble the head. The first operation in repacking a head is to disconnect the tinsel connecting leads. In

some models, the permanent magnet can then be removed. A keeper should be put across it immediately and left there until

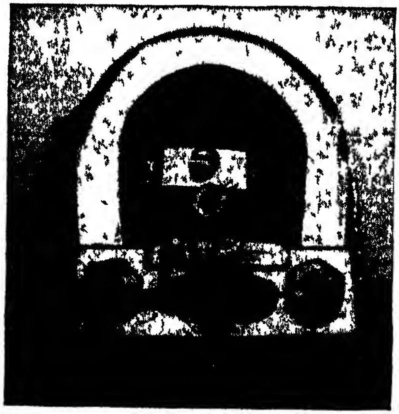


FIG 256 —Magnetic pickup—rubber damped

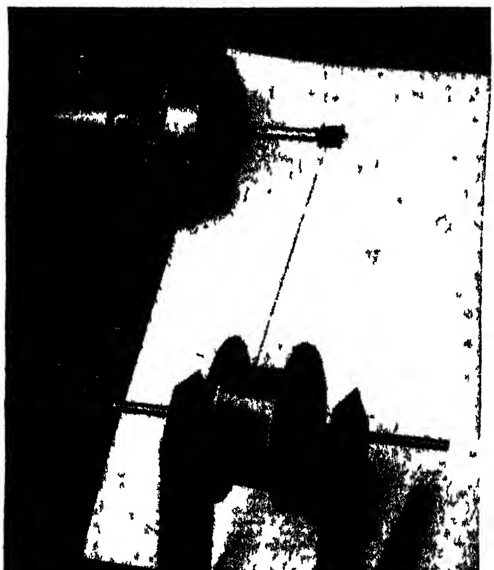


FIG 257 —Jig for winding phonograph and earphone coils

the head is reassembled. The leads to the coil should then be unsoldered. The rest of the retaining screws can then be removed. Considerable care is necessary in removing the coil

to prevent damage to it. As soon as it is loose, it should be put in a small box or in some other place where it will not be damaged. If the coil should be open, it can be easily rewound by making a mandrel for it that will fit in a hand drill. The wire used can often be salvaged from the secondary of an old audio transformer. The old transformer coil should be placed on some

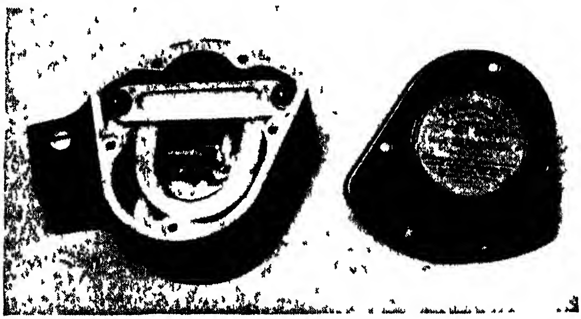


FIG 258.—Magnetic pickup—oil damped.

FIG. 259.—Coils from pickup shown in Fig. 258.

kind of jig that will allow it to unwind with very little tension, or trouble will be experienced with the wire breaking. It really saves time to make a suitable jig in the first place. When the head is reassembled, it is essential that the armature be held exactly in the center of the space between the poles and that the rubber be flexible enough so that it can move easily. However, the armature should be held securely enough so that it will not strike the pole pieces.

Oil-damped Pickup.—Figure 258 shows the interior of an oil-damped pickup with the oil removed. Figure 259 shows what the coils look like when they have 115 volts a-c put across them. Figure 260 shows the coil forms mounted on the cores, which are in turn mounted on the north pole of the permanent magnet. The south pole piece in the form of a ring has been added in Fig. 261. The phonograph needle is mounted on a steel diaphragm placed just above the ring and cores so that the point is to the right in Fig. 261. As the needle follows the groove, the diaphragm rocks and closes the gap first between the core of one coil and the ring and then the other This varies the flux through the coils and generates the corresponding voltage in them. The only damping used in this pickup is a heavy mineral oil that nearly fills the case.

FIG 260 —Partial assembly of pickup shown in Fig 258.

Photoelectric Reproducer.—The Philco photoelectric reproducer shown in Fig. 262 has three main parts: a source of light A, a very light mirror B mounted on the shaft of the jeweled needle, and a photocell C to change the flickering light into a pulsating voltage. The problem of avoiding hum due to the exciting current of the light source is cleverly solved by using r-f current to light the bulb. The circuit is shown in Fig. 263. Since the frequency of this current is far above any audible frequency, no hum is heard even if the photocell is capable of reacting to light fluctuations at that speed, which is doubtful.

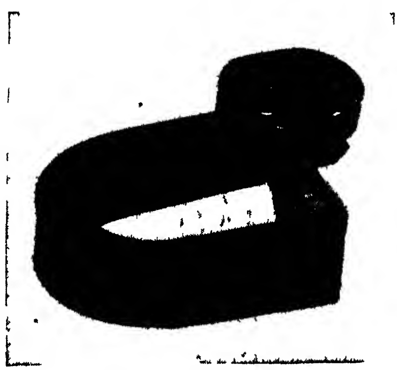


FIG. 261.—A further stage in the assembly of the pickup shown in Fig. 258.

Photoelectric Reproducer Adjustments.—To reproduce the sound from a record, the light beam of the reproducer should be carefully positioned on the light-sensitive cell. If the light beam is not carefully set, the sound reproduction will be distorted, weak,

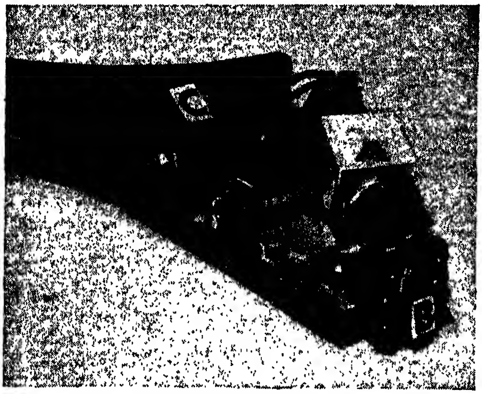


Fig. 262.—The Philco photoelectric reproducer.

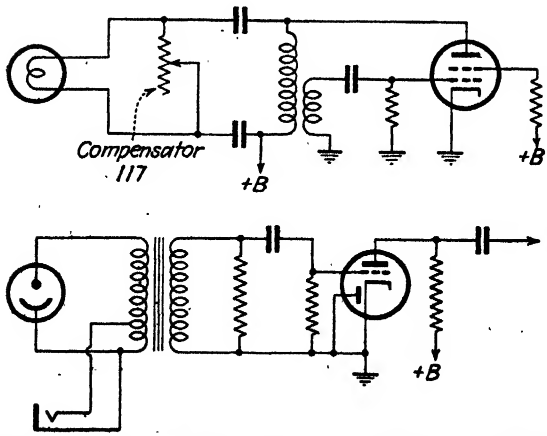


Fig. 263.—Circuit diagram of Philco photoelectric reproducer.

or if the light beam is completely on or off the cell, the phonograph will be silent.

If any of these conditions exist, the following adjustment procedure should be made:

Note.—These adjustments should be made with the power-line voltage at 118 volts a-c.

1. *Adjusting the width of the light beam.* To make this adjustment push the lamp socket assembly into its holder until a clear image of the lamp filament appears on the light cell. The socket should then be slightly pushed in beyond this point until the rectangular spot of light is $\frac{5}{32}$ in. in width. The socket assembly is now rotated so that the spot of light is vertical.

2. *Positioning the light beam.* To position the light beam on the light cell, turn the adjusting screw at the lower left side of the reproducer until the spot is half on the cell and half on the metal frame surrounding the cell.

3. *Adjusting the intensity of the lamp.* When shipped from the factory, the lamp of the reproducer is adjusted for best operating efficiency. The intensity of the light from the lamp is adjusted by compensator No. 117 (Fig. 263), located on the rear of the radio chassis. Under ordinary circumstances, an adjustment will not be necessary. When the reproducer or lamp is being replaced, however, there may be a tendency toward microphonic feedback. In this case the compensator is adjusted as follows:

a. Turn the volume control on full and play a record.
b. While the record is playing, turn compensator No. 117 in the direction necessary to eliminate microphonic feedback. By turning the compensator the strength of the pickup output is increased or decreased.

4. *Installing new lamp.* When installing a new lamp in the socket, there are two positions in which the lamp can be inserted. Ordinarily, either of these positions can be used. In some cases, however, due to the lamp filament being off center, the lamp should be inserted in the position that gives the best centering of the spot of light on the vibrating mirror.

Servicing the Crystal Pickup.—There is nothing that a serviceman can do to a defective crystal pickup aside from possibly replacing worn or broken leads. In checking a crystal pickup, care should be taken to keep any voltage except extremely low voltages off the crystal or it will be broken. And this caution includes the use of ohmmeters!

Since the output of a crystal pickup has a peak at low frequencies, it will accent these frequencies. In some cases this characteristic will cause the output to contain gear and motor noise. The l-f output can be controlled by the value of the load

resistor across the pickup. The lower the value of this resistor the less of the low frequencies will be reproduced. Conversely, if accentuated base response is desired, a high load resistor—up to 10 megohms—should be used. If this resistor is also used as a grid leak, care should be taken not to exceed the resistance allowed in the grid circuit of the first tube. This value can be obtained from manufacturers' tube data.

Installing Headphone Outlets on Radio Sets.—There are many situations that make it desirable to add a headphone outlet to a radio set—for listening late at night without disturbing others, for invalids, for hard-of-hearing persons, and in hospitals and similar institutions. For different situations the circuit will have to be modified to provide satisfactory service. In some cases the phones and the speaker should be working simultaneously; in others it is desirable to have the speaker in the set quiet while the phones are operating. In that case a dummy load should be provided so that the voltages across the output transformer will not rise to destructive values. Figure 264 gives the schematic diagram of a circuit that disconnects the speaker when the headphones are inserted in the jack and connects a dummy load across the speaker.

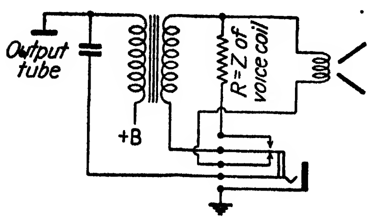


FIG. 264.—Circuit diagram of a headphone jack.

Interesting Circuit Diagrams.—The following circuit diagrams are included because they illustrate special circuits or have other interesting features.

The circuit shown in Fig. 265 illustrates the use of a 6B7 tube as an i-f amplifier, a diode detector, audio amplifier, and noise suppressor. The diagram is a portion of the schematic circuit of the Emerson model 678 autodynamic superheterodyne. The signal is first fed onto the grid of the pentode portion of the tube. The plate circuit feeds into the primary of an i-f transformer, the secondary of which feeds the diodes. The condenser C by-passes the intermediate frequency back to the cathode, for it could not get through the primary of the audio transformer. The audio frequencies appear across the volume-control resistor R and are fed back to the grid of the same tube through the condenser C_1.

The audio output of the tube appears across the primary of the audio transformer T_2, for the intermediate transformer T_1 offers very little impedance to audio frequencies. The lower diode plate acts as a shorting rectifier and supplies the a.v.c. voltage.

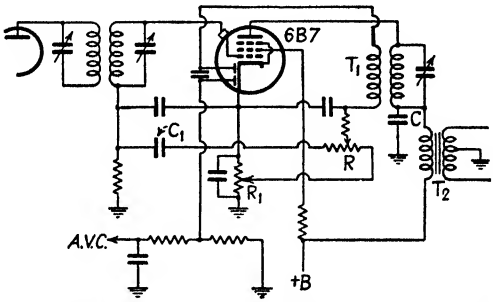


FIG. 265.—Circuit diagram illustrating reflex operation of a vacuum tube.

The resistor R_1 is used as a noise suppressor. When the arm is at any position except at the top, the detector diode is biased negatively in respect to the cathode, and no diode current can flow until the peak signal voltage is larger than this negative bias.

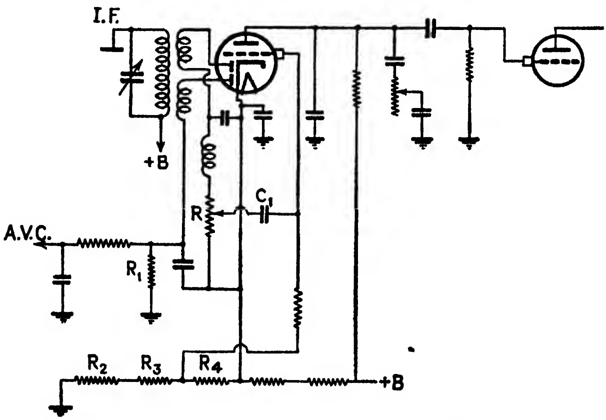


FIG. 266.—Circuit diagram using separate coils to feed the diodes used for detection and a.v.c.

An example of the use of separate coils to feed the diode plates is shown in Fig. 266, which is a portion of the schematic circuit of the Majestic model 460. The upper diode acts as the detector. The audio frequencies appear across the volume

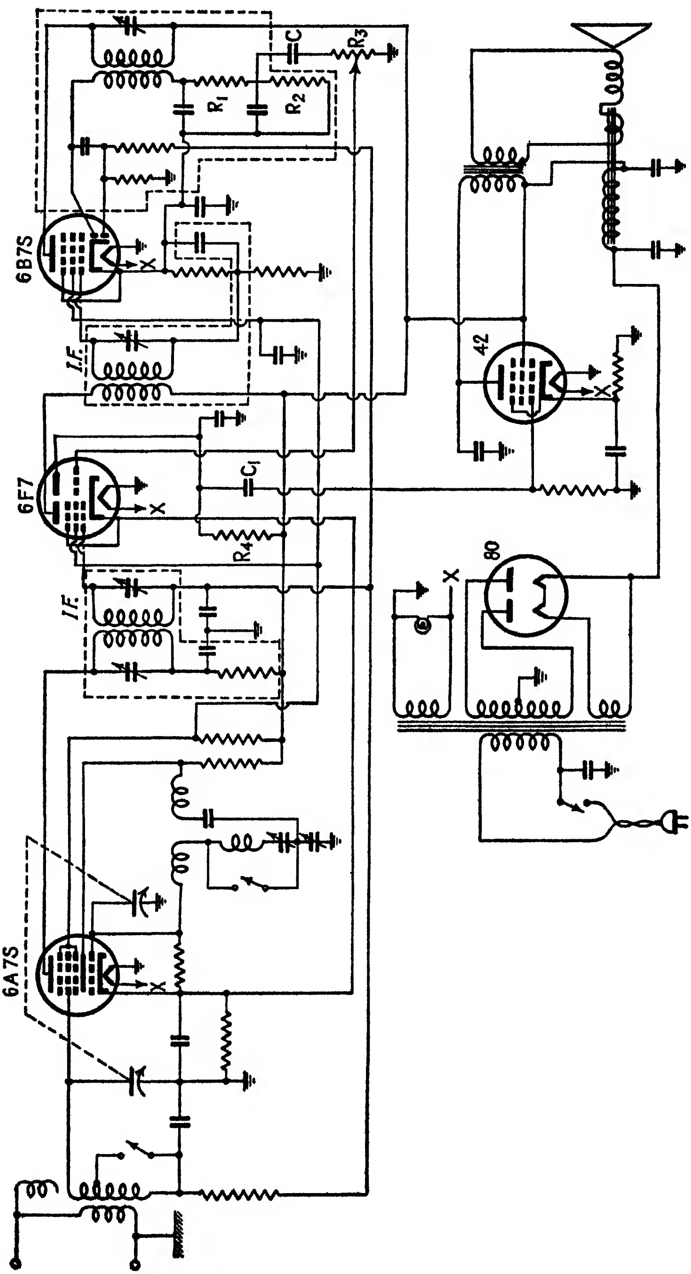


FIG. 267.—Circuit diagram of a superheterodyne receiver using a reflex circuit involving two tubes.

control R and are fed through the condenser C_1 to the grid of the audio amplifier tube. The lower diode furnishes the a.v.c. voltage. R_1, R_2, R_3, and R_4 are the load resistors for this diode. The resistors R_2, R_3, and R_4 place a negative bias on this diode so that delayed a.v.c. is secured, because the peak signal voltage must be larger than this bias before any a.v.c. voltage can be secured.

The circuit shown in Fig. 267 was chosen because of the application of the 6F7 tube in a reflex circuit. Modern reflex circuits differ from the older types in that the signal is returned to a different set of elements in the tube rather than to the same set, as was the custom previous to the advent of the duplex tubes. In this circuit, the i-f signal is impressed on the grid of the pentode portion of the 6F7 tube. The plate circuit of this tube feeds into the i-f transformer, the secondary of which feeds the signal into the grid of the 6B7S tube. The plate circuit of this tube feeds the primary of another i-f transformer, the secondary of which feeds the diodes. The upper diode provides detection, and resistors R_1 and R_2 are the load resistors. A portion of the voltage is fed through the condenser C into the volume control R_3. This feeds the audio frequency back onto the grid of the triode portion of the 6F7 tube, which is resistance-coupled to the input of the 42 cutput tube, R_4 being the plate resistor and C_1 the blocking condenser.

Figure 268 shows the schematic diagram of a two-band radio-phonograph public-address combination. The two-point four-gang switches select either the broadcast or short-wave band. The selector switch *MPR* controls the use of the radio tuner, the phonograph pickup, and the microphone. The arm T_1, which is on the same shaft as the arm T, grounds the radio tuner output when either of the other two signal sources is in use. When the cutting head is being used, the speaker can be disconnected by the switch X, which connects a resistor across the output to prevent the voltage from building up and damaging the output transformer. In the same manner, when the cutting head is not in use, it is disconnected by the switch Y, which connects a condenser across the output to replace the capacitive reactance of the crystal cutting head. Owing to the low output of the crystal microphone, a 6J7 is used to bring the level of the signal up to that of the other sources. The 6U5 is used as a volume indicator

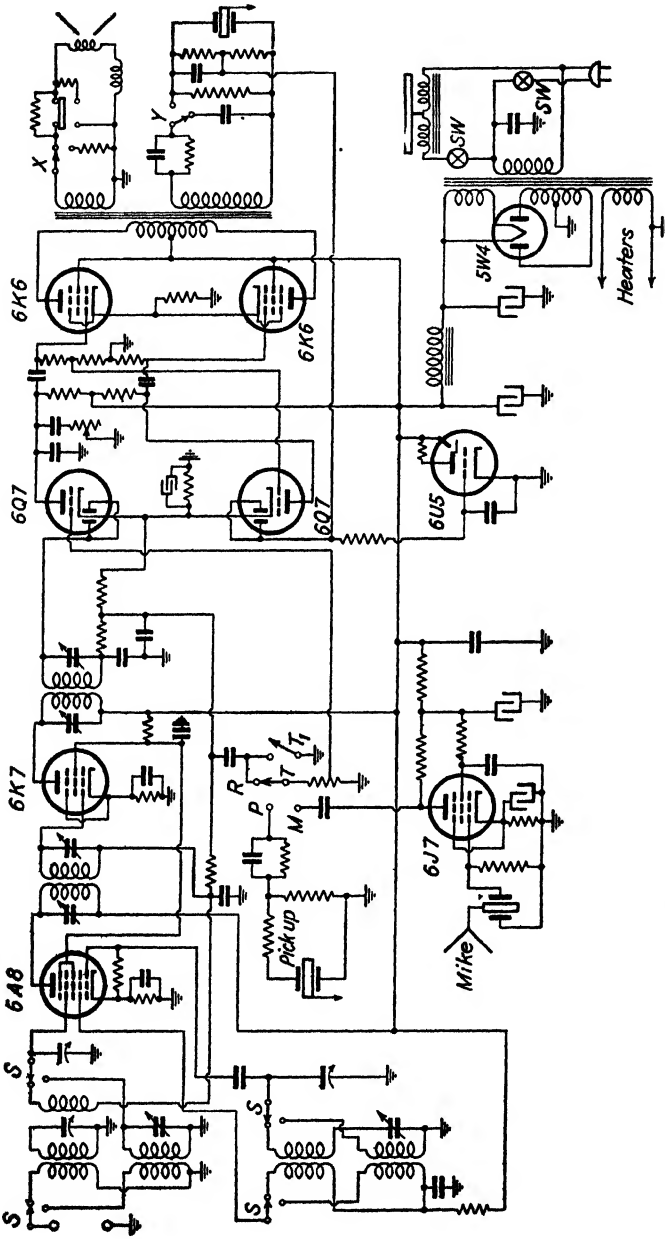


FIG. 268.—Schematic diagram of the Wilcox-Gay model A70 Recordio.

in cutting records. Note the equalizing circuits for the crystal pickup and recording head.

Figure 269 shows the schematic diagram of a more complicated radio-phonograph public-address combination. It illustrates the

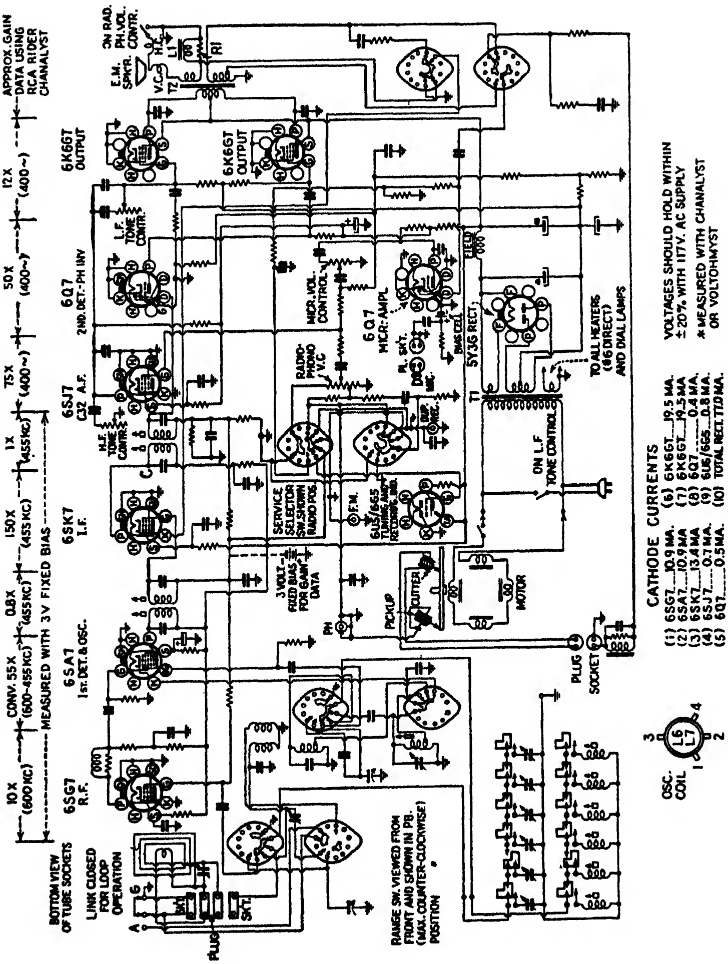


FIG. 269.—Circuit diagram of a radio-phonograph public-address combination.

use of a different style of symbols for the tubes and also shows the usual method of indicating the connections to a multipoint multi-gang switch. Figures 270 to 274 give a breakdown of the complete circuit and show the connections for each different function.

Figure 275 indicates the switch positions for using the various combinations of facilities. It will be noted that two programs can be mixed with this circuit.

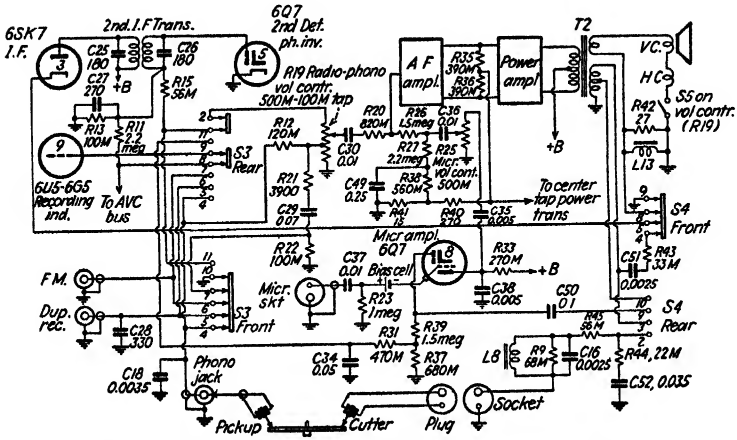


Fig. 270.—Radio. (*Courtesy of RCA Manufacturing Co., Inc.*)

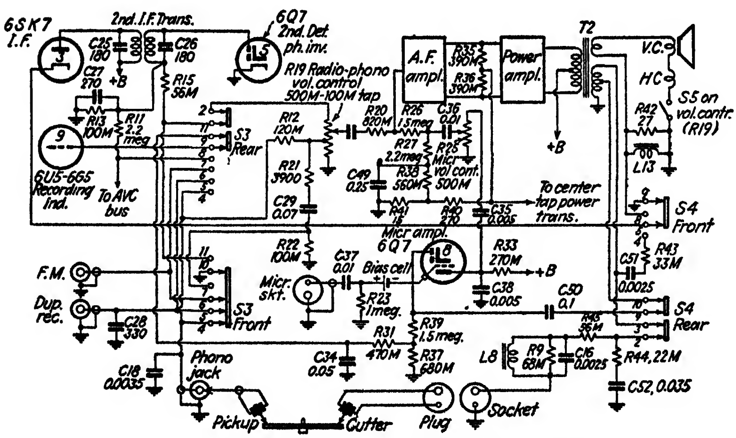


Fig. 271.—Radio recording. (*Courtesy of RCA Manufacturing Co., Inc.*)

Provision is made for the use of a loop or external antenna. Six stations may be tuned in by push buttons, using trimmers to tune the r-f circuit and permeability-tuned coils for the oscillator.

An examination of the "breakdown" circuits will show that interference from the radio tuner when using the phonograph or microphone is prevented by opening the cathode circuit of the last

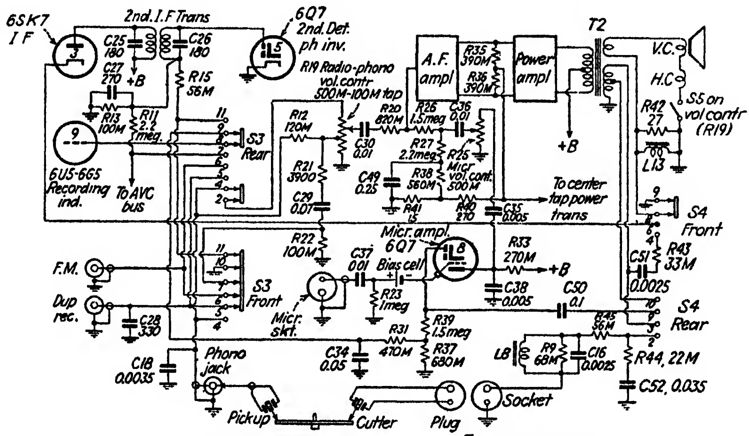


FIG. 272.—Phonograph. (*Courtesy of RCA Manufacturing Co., Inc.*)

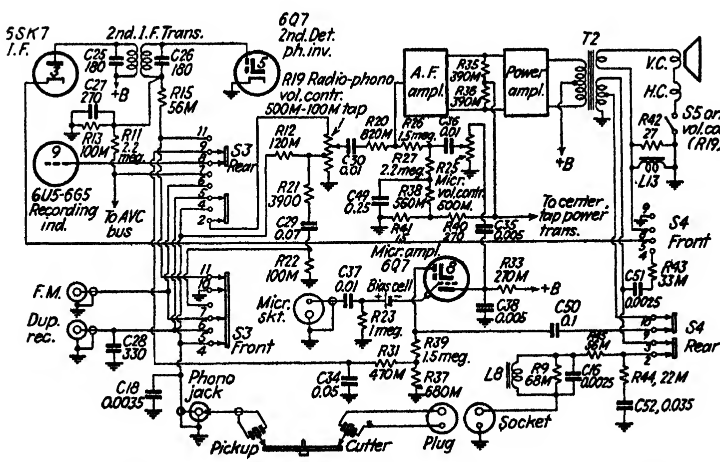


FIG. 273.—Recording. (*Courtesy of RCA Manufacturing Co., Inc.*)

i-f tube. When the selector switch is set for recording of any kind, the choke L1 and resistor R1 are inserted in series with the voice coil to allow the program being recorded to be monitored at a reduced volume. The 6U5/6G5 gives a visual indication of

the volume for recording. A jack is provided for an auxiliary pickup so that new records can be cut from old ones or a recording made from a record mixed with voice from the microphone. A

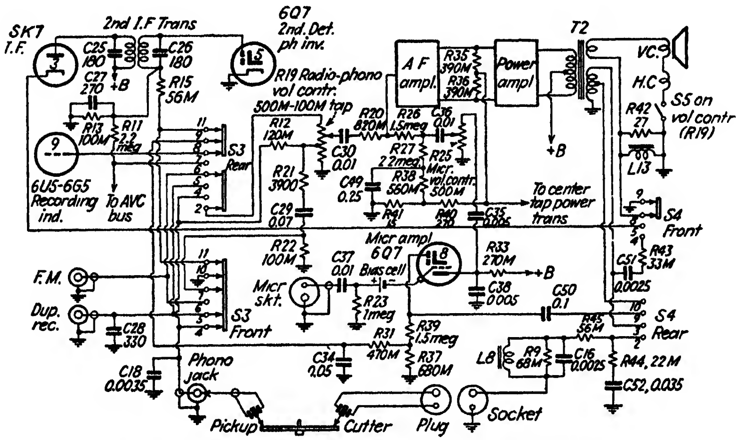


FIG. 274.—FM or television. (*Courtesy of RCA Manufacturing Co., Inc.*)

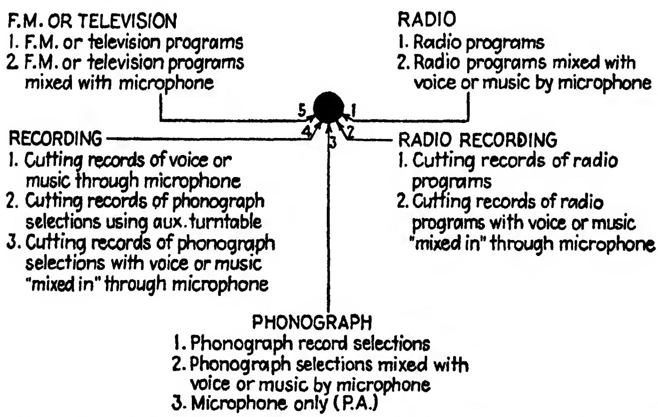


FIG. 275.—Operating positions of the switch. (*Courtesy of RCA Manufacturing Co., Inc.*)

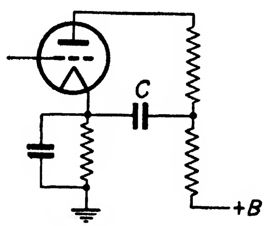
second jack is provided for the output of an FM tuner or for the audio signal of a television receiver.

REVIEW QUESTIONS

14-1. Describe the process of making a good radio solder joint.
14-2. What flux is used for

a. Radio work?
b. Electrical wiring and motor circuits?
c. Sheet iron?

14-3. What is the purpose of a flux?
14-4. What is the proper procedure to follow in servicing a set?
14-5. How can a source of hum or a microphonic tube be quickly located?
14-6. How can the difficulty in a dead set be quickly located?
14-7. What is meant by signal tracing?
14-8. Show a circuit of a simple audio oscillator.
14-9. Why are the readings of a 1,000 ohms per volt voltmeter unreliable in a resistance-coupled amplifier?
14-10. Why should a serviceman know the customary or usual values of the various resistors and condensers in a radio receiver?
14-11. Describe an emission-type tube checker.
14-12. Describe a grid-shift tube checker.
14-13. Describe a dynamic mutual-conductance tube checker.
14-14. What is the best check on a tube?
14-15. What can be done if a few turns on the voice coil of a speaker becomes loose?
14-16. How can the spots where the plates of a tuning condenser touch each other be located?
14-17. In a receiver, having a circuit as shown in the accompanying figure, the condenser *C* was found completely shorted. What parts should be replaced? Why?



14-18. Describe a method of checking electrolytic condensers with an ohmmeter.
14-19. Why should t.r.f. receivers be aligned?
14-20. Name two procedures for aligning t.r.f. receivers and describe one method in detail.
14-21. Under what circumstances will the indications of an audio-type output meter be unreliable?
14-22. What precautions should be used if the a.v.c. circuit is disconnected?
14-23. In aligning a t.r.f. receiver where is the test oscillator connected and to what frequency is it tuned?
14-24. In aligning a t.r.f. receiver show two connections for an audio output meter.

14-25. What can be done to overcome the effect of the a.v.c. circuit on the output meter?

14-26. Explain two methods other than an audio-type output meter of checking the alignment of receivers having a.v.c.

14-27. State the general order of procedure in aligning a superheterodyne.

14-28. In aligning the i-f amplifier where is the test oscillator connected? What precautions should be taken with this connection?

14-29. What type of output indicator is used, where is it connected, and why is that type used?

14-30. What part of the superheterodyne alignment corrects the dial settings?

14-31. To what is the test oscillator connected for the alignment of the oscillator?

14-32. To what frequency or frequencies is the test oscillator tuned for aligning the oscillator of a superheterodyne on the broadcast band?

14-33. To what is the test oscillator connected for the alignment of the r-f circuits of a superheterodyne receiver?

14-34. What special procedure is necessary when aligning the oscillator of a superheterodyne receiver?

14-35. How can the intermediate frequency of a superheterodyne receiver be determined if it is not known?

14-36. Describe all connections to the oscilloscope when using it for i-f alignment.

14-37. Describe all connections to the test oscillator assuming that a motor-driven "wobbulator" condenser is used.

14-38. Show a circuit of the padders for an oscillator using an air-core coil.

14-39. Show a diagram of the oscillator circuit with an iron-cored coil with the h-f and l-f adjustments indicated.

14-40. In what type of circuits is the order in which the various bands are aligned important? Illustrate by diagram if necessary.

14-41. Why is the use of a dummy antenna between the test oscillator and the receiver necessary for accurate alignment?

14-42. What is the order of procedure for aligning an FM receiver?

14-43. Describe the procedure for aligning the limiter stage of an FM receiver with an unmodulated oscillator and output indicator.

14-44. Describe in detail the procedure for aligning the primary of the discriminator transformer in an FM receiver using an unmodulated oscillator.

14-45. Describe in detail the procedure for aligning the secondary of the discriminator transformer in an FM receiver using an unmodulated oscillator.

14-46. Describe in detail the procedure for visual alignment of the i-f amplifier of an FM receiver.

14-47. Describe in detail the connections and the procedure for visual alignment of the discriminator of an FM receiver.

14-48. Under what circumstances are high-gain i-f transformers used? When are low-gain i-f transformers used?

14-49. Give the standard color code for the leads on i-f and r-f transformers.

14-50. Which leads from an r-f or i-f transformer should be most carefully placed to avoid oscillation?

14-51. In replacing a coil in an i-f transformer what would a lack of selectivity indicate?

14-52. In replacing a coil in an i-f transformer what would a lack of volume or gain indicate?

14-53. Name three types of push-button tuning schemes.

14-54. Describe the procedure for adjusting the push buttons when permeability tuning is used.

14-55. What precaution should be taken in many a-c d-c battery receivers when replacing a tube?

14-56. Name two causes of dead spots on the tuning dial of a superheterodyne receiver.

14-57. How can a change in the volume of a receiver caused by turning certain house lights on or off be eliminated?

14-58. Name five causes of intermittent operation.

14-59. Describe in detail the use of a Chanalyst or Analyst in locating the cause of intermittent operation.

14-60. What effect would an open-filter condenser have on the a.v.c. line?

14-61. How can the operation of the a.v.c. circuits be checked?

14-62. Give at least ten sources of hum in a receiver.

14-63. Describe a method of quickly determining whether or not the *B* supply filtering is sufficient.

14-64. How can a stage in an audio amplifier, which is originating hum, be quickly located?

14-65. What difficulty is encountered in the reception of high-fidelity programs?

14-66. Is high sensitivity desirable in a high-fidelity receiver? Why?

14-67. Describe at least one method of varying the selectivity of a high-fidelity receiver.

14-68. How is the percentage of feedback in inverse feed-back circuits controlled?

14-69. (*a*) What effect would too much feedback have on the volume and quality of the output? (*b*) What effect would too little feedback have?

14-70. Show a circuit of an AM phonograph oscillator.

14-71. Describe the operation and adjustment of the Philco photoelectric reproducer.

14-72. What precaution should be taken in using and servicing crystal phonograph pickups?

14-73. Show a circuit for installing a headphone outlet on a radio that will mute the speaker when the phones are used.

CHAPTER XV

PUBLIC-ADDRESS SYSTEMS

Main Parts of System.—The essential parts of a public-address system are a microphone, suitable audio amplifiers, and one or more speakers. The more elaborate outfits include faders, volume indicators, and monitor amplifiers. Often a magnetic phonograph pickup is included with a suitable input connection. Figure 276 gives a block diagram of a public-address system.

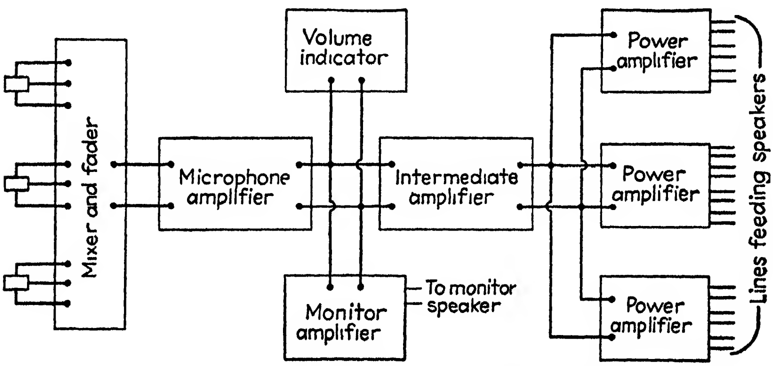


FIG. 276.—Block diagram of a public-address system.

On the larger and on many of the medium-sized systems such as are used in small theaters, all these parts are on separate chassis. In the smaller systems, they are combined on one chassis or are omitted. The mixer may be of the transformer type or it may be of the electronic type. The latter type is becoming very popular because there are no coils in it to pick up hum, which is one of the main difficulties of the transformer type. The microphone amplifier is often just a single-stage amplifier using any of the pentode-type tubes having high gain and is mounted on the chassis with the rest of the amplifier. The volume indicator may be a single-stage amplifier, which operates an output meter, or it may be only a small rectifier, which rectifies a portion of the output. The d-c voltage thus

obtained is used to bias the grid of an electron-ray tuning indicator such as the 6E5. The monitor amplifier is dispensed with in all but the largest systems. Usually a small speaker is connected to the output of the amplifier for monitoring purposes. The output may consist of a single stage of push-pull or parallel push-pull, or, if a large amount of power is required, several push-pull stages may be connected in parallel.

In some cases, each microphone has a separate amplifier, and the mixer and fader are between the microphone amplifiers and the intermediate amplifier.

Each of these parts will be considered separately.

Microphone.—There are five types of microphones in use: the carbon, the condenser, the ribbon, the dynamic, and the crystal. Some microphones have both dynamic coils and a ribbon. The proper use of these two types produces a microphone that is sensitive to sound coming from one side only. The proper selection of the microphone to be used for any particular use will largely determine the success of the operation. Owing to their construction, ribbon microphones are not adapted to use outdoors or in a breeze for the breeze will move the ribbon and cause noise in the output. The silk shield inside the case overcomes this trouble to some extent but not completely. The crystal microphone will cease to function if the temperature gets much over 100°F. This means that this microphone cannot be used out in the sun or in any location where the temperature is high. A dynamic microphone can be used successfully in either of these situations. The outstanding characteristics of each microphone will be discussed in separate sections. However, it should be realized that there is a vast difference in the characteristics of microphones of the same type. The shape, size, and materials used in the mounting will have a great effect on their performance.

Carbon-granule-type Microphone.—A cross section of the carbon microphone is shown in Fig. 277. *A* and *B* are two heavy steel rings. The ridge in one and the groove *D* in the other hold the diaphragm *C* very tightly. The diaphragm is made of a very tough steel alloy and is about 0.001 in. thick. The ring *G* is screwed into the ring *B*. It is used to adjust the tension on the diaphragm so that its natural period of vibration is above the desired audio range. The center of the diaphragm is gold-

plated on each side to ensure good contact. The back of the microphone is closed except for a ring of holes that allow the air and sound to reach the back of the diaphragm. The bridge *E* extends across the opening in the front of the microphone and supports the front carbon granule cup or button *F*. A similar one is supported by the back. These cups do not quite touch the diaphragm. They are partly filled with fine carbon grains. Soft felt washers *H* prevent the carbon from getting out of the cup.

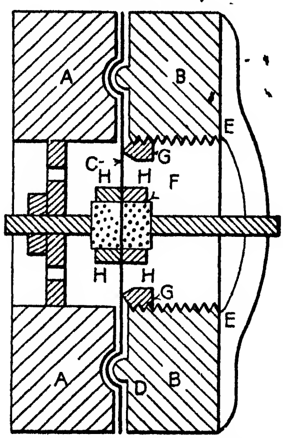


FIG. 277.—Cross section of a two-button carbon microphone.

Connections.—The connections of this microphone are shown in Fig. 278. One wire is connected to the frame and diaphragm and one to each of the two buttons. The current passes through the carbon grains in each button. Notice particularly that the buttons are in parallel for the direct current. Each button is in a separate circuit fed from a common battery. The closed-circuit jacks *A*, *A* allow the use of a single meter for reading the current on both buttons of the microphone by inserting a plug connected to the meter. The rheostat *B* is used to adjust the current to the proper value. The diagram shows the microphone connected directly to the microphone amplifier. If a mixer and fader are used, a pair of jacks and a rheostat, as shown in Fig. 278, must be provided for each microphone connected to the amplifier.

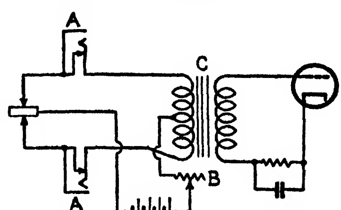


FIG. 278.—A circuit showing one method of reading the current in the two buttons of a two-button carbon microphone.

The input transformer *C* must have an impedance looking into the primary of several times 200 ohms to match the microphone and 400,000 to 500,000 ohms looking into the secondary to match the grid impedance of the tube used.

In many cases, it will be found that the use of an input transformer mounted on the amplifier chassis will cause a bad hum.

This can be reduced by turning the transformer at some angle that can be found only by experiment. Increasing the shielding around the transformer also aids in the reduction of the hum; however, a shield at least ⅜ in. thick will be required unless it is made of a material having high permeability. One method to solve the difficulty is to use the circuit shown in Fig. 279, which does not require a transformer and so is not as subject to hum pickup. The resistance R should be as large as possible and still allow the proper amount of current to reach the microphone. The microphone current-control rheostat R_1 will have to be practically the same size as the resistances R to get the proper variation in the current.

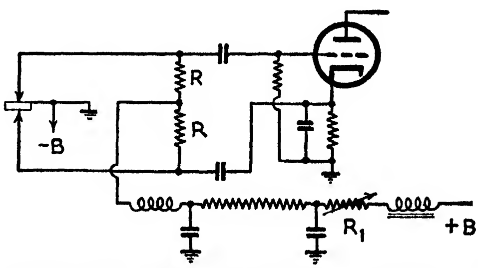


FIG. 279.—Circuit using resistance coupling for a carbon microphone.

Theory.—The operation of the microphone is as follows:

The sound waves striking the diaphragm cause it to vibrate in unison with them. This vibration causes the carbon grains on one side of the diaphragm to be compressed, thereby lessening the resistance. At the same time, the grains on the opposite side are loosened, thereby increasing the resistance. This action causes more current to flow through the first button and less through the second button. These two varying currents are then passed through the primary of the microphone input transformer in such a way that their effects add together in the secondary of the transformer in the same way that the plate currents in a push-pull output stage do in the output transformer.

Notes on Use and Care.—Never allow more than 20 ma. to pass through each button of the microphone. To do so will cause the carbon grains to stick together—a condition known as a "packed mike." Never use any more current than is absolutely

necessary. The less current used, the less will be the hiss in the output. Never put two microphones in series or in parallel on the same leads. Never jar a microphone severely when direct current is flowing through it; such a disturbance is liable to pack it. For best operation, the current should be the same through each button. If the current is not the same on both sides, it should be turned off and the microphone shaken while it is held in various positions, particularly upside down. This shaking has a tendency to loosen any of the carbon grains that are packed together. In this treatment, care should be used to see that the other side of the microphone is not packed. This will make the current reading on the two sides alike, but the response from the microphone will be weak, as well as inferior in quality. It is better to use a microphone that has unequal current in the buttons with only one side packed than it is to have the current equal and have both sides packed. Never move a microphone with the current turned on if it can be avoided. Whenever a microphone is to be connected or disconnected from the circuit, always adjust the microphone current rheostat to the maximum resistance position. This is best for the microphone, and it reduces the click in the output. Always support a microphone on an elastic support. Many operators prefer rubber bands to springs, because springs sometimes cause a metallic ringing noise in the loud-speakers. If rubber is used, it should be frequently inspected for signs of aging and rotting or it may break unexpectedly and let the microphone fall.

After a period of use, usually about a year, if the microphone has had fairly constant use, the carbon grains become roughened and do not separate when the diaphragm springs away from them. This difficulty can be remedied by replacing the grains. If the same quality is desired, it will be necessary to use grains of the same degree of fineness. After the diaphragm has been in place for several years whether it is used or not, it will lose its tension owing to elastic fatigue. There is no way of tightening the diaphragm except to install a new one. In fact it does not pay to replace the carbon grains without also replacing the diaphragm. Owing to the hiss in the output and the necessity of having some source of microphone current, this type of microphone is little used at the present time.

CHARACTERISTICS OF CARBON MICROPHONE

ADVANTAGES	DISADVANTAGES
Low cost	Hiss
Small amount of associated equipment	Will not transmit so great a range of frequencies as the other types
Very sensitive	
Has the largest output voltage	

Condenser-type Microphone.—The condenser microphone consists of a heavy back plate and a thin stretched diaphragm placed in front of the back plate with about 0.001 in. between them. The diaphragm and back plate are well insulated from each other and form the two plates of a condenser.

Theory of Operation.—The circuit diagram is shown in Fig. 280. Inspection of the diagram shows that the microphone and the two resistors *A* and *B* are in series across 180 volts. Sounds striking the diaphragm of the microphone cause it to vibrate. This vibration changes the spacing of the plates and therefore the capacity. As the capacity increases, more current is drawn through resistor *A* to charge the condenser. As the capacity decreases, the current is forced out of the condenser. This charge and discharge of the condenser cause a varying *IR* drop in the resistor *A*. This *IR* drop, which is very small, is passed on to the tube by the standard resistance coupling. Two stages of amplification are usually necessary to bring the signal up to the volume delivered by a carbon microphone. Because the leads between the microphone and the grid of the first tube must be short, in order to keep the noise pickup less than the signal, the amplifier is mounted in a cabinet forming the base of the microphone stand.

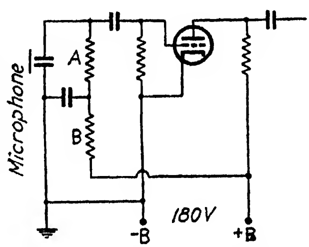


FIG. 280.—Input circuit for a condenser microphone.

Notes on Use and Care.—The main difficulty with this microphone is due to moisture condensing between the diaphragm and the back, thereby causing shorts. It is also necessary to watch the *A*, *B*, and *C* voltages of its amplifier and the condition of the tubes.

This microphone is little used at the present time mainly because of the necessity for battery operation to avoid hum.

Six-volt storage batteries are used for the filaments of the tubes and dry-cell *B* batteries for the plate supply. These make a heavy and bulky load to transport. The high voltage in the cable also make it rather dangerous, owing to the fire risk from shorts caused by walking on the cable.

Advantages	Disadvantages
Very good fidelity	Low sensitivity
No hiss	Special amplifier and high-voltage battery
	Insulation difficulties due to atmospheric conditions

Ribbon Microphone.—The ribbon microphone illustrated in Fig. 281 consists of a powerful horseshoe-shaped electromagnet or permanent magnet *A* with special pole pieces between which a thin corrugated ribbon of metal *B* is suspended. The ends of this ribbon are connected to the primary of a special step-up transformer. Figure 282 illustrates a ribbon microphone with the front cover removed.

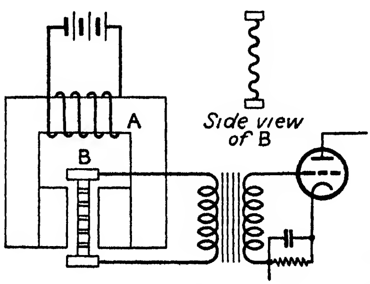


Fig. 281.

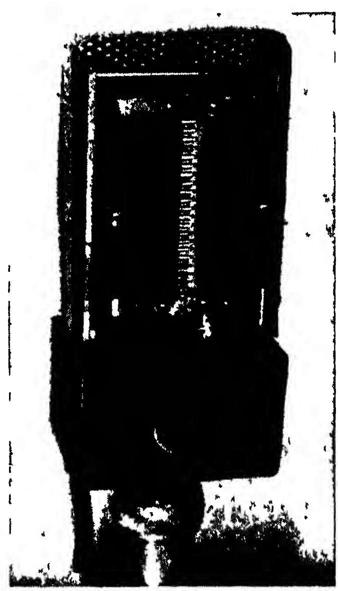


Fig. 282.—A ribbon microphone with the front cover removed.

Theory of Operation.—The sound striking the ribbon causes it to vibrate and to cut some of the magnetic lines of force between the pole pieces. This action generates a voltage in the ribbon that is passed to the grid of the first tube by means of the special step-up microphone input transformer.

Notes on Use and Care.—This microphone should be shielded from any draft of air that would tend to vibrate the ribbon. The microphone should be placed so that the sound it is to pick up strikes it at right angles. Sounds coming from the side of the microphone have practically no effect on it. This is known as a "directional effect." This directional property can often be used to an advantage. For example, in broadcasting an orchestra, it is often desirable to reduce the pickup of the brass instruments and accent the strings. This can be accomplished by placing the microphone so that it faces the string section and so that the side of it is toward the brass instruments. The directional characteristic makes the microphone suitable for picking up a single speaker provided he will stay in one spot. However, it is too directional satisfactorily to pick up a chorus or even a quartet unless it can be placed some distance in front of them. When used at the front of a stage it has the disadvantage of picking up any noise in the audience such as coughing or rustling of programs.

Advantages	Disadvantages
Due to its directional properties, unwanted noise can sometimes be eliminated by properly placing the microphone	This microphone is not adapted for outdoor use because even a slight wind would blow the diaphragm out of place
This microphone has very excellent quality	

Dynamic Microphone.—The dynamic microphone is constructed along the same lines as a dynamic speaker. It consists of a self-supporting aluminum coil placed in a very strong permanent magnetic field. The coil is fastened to a small, specially shaped diaphragm.

Theory of Operation.—Any sound striking the diaphragm causes it to vibrate, and this vibration moves the coil back and forth in the magnetic field. Since the coil is cutting lines of force, a voltage is generated, which causes a current to flow in the primary of a transformer connected to it. The secondary of the transformer is in the grid circuit of a tube.

Figure 283 shows a dynamic microphone with a case that gives it nondirectional properties. Used as shown and in the position shown, it will pick up sound equally well from all sides

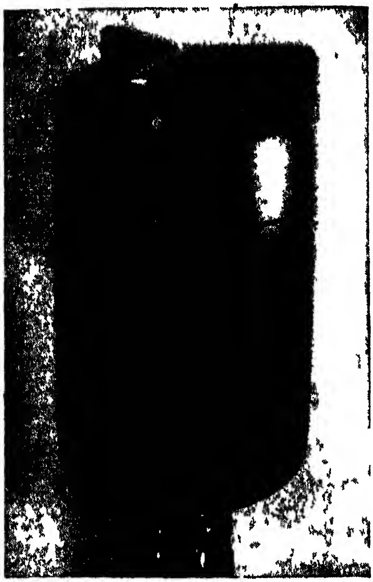


FIG 283 – A dynamic microphone with nondirectional properties

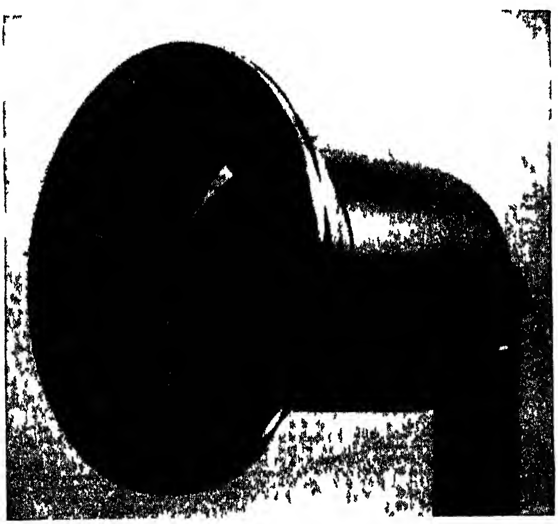


FIG. 284.—A ring added to the microphone in Fig. 283 gives it marked directional properties.

and from above. Figure 284 shows the same microphone tipped over and a special ring added to give it marked directional properties. This microphone therefore is very convenient to use for general work for the characteristics of it can be altered to suit the condition. Figure 285 shows another dynamic microphone that has unidirectional properties. This means that it will pick up sound within a 180-deg. range in front of it but is almost entirely dead to sound coming from the back. The unidirectional property makes a microphone very suitable to use on a stage or platform where it is desirable to avoid picking up any noise in the audience.

FIG 285—Unidirectional dynamic microphone.

Notes on Use and Care.—The only care that is required is to keep the leads of this microphone in good shape.

ADVANTAGES

No hiss as in the carbon mike
No danger of packing if it is moved while in use
No microphone amplifier is needed as with the condenser microphone
It is not affected by weather conditions as a condenser microphone
No exciting current is needed
It is very small and light in weight
The quality is very good

DISADVANTAGES

The output is about 100 db down, which, interpreted, means that it must be amplified more than other microphones, except the ribbon microphone, before it reaches headphone volume

Microphone Preamplifier.—With proper input and output circuits, any good audio amplifier can be used as a microphone amplifier. The power supply for the preamplifier, whether it is one or more stages, must be extremely well filtered, for the slightest hum introduced in this amplifier will be amplified by all the succeeding stages and will be very objectionable at the

speakers. For the same reason, all the leads in this amplifier must be carefully shielded, and the whole amplifier must be kept as far away as possible from any source of electrical disturbance caused by power transformers, filter chokes, and a-c leads. These considerations, in many cases, lead to the placing of the amplifier on a separate chassis, especially when the output must be particularly free from hum. All parts such as resistors, condensers, and tube sockets must be of the highest quality; otherwise they are certain to introduce noise into the amplifier. All soldered joints must be very carefully made to avoid rosin joints. Do not allow any rosin to remain on the joints to cause corrosion. The insulation between all of the circuits and the chassis must be of a high order, or leakage will cause noise.

Output Circuits.—Where the program has to be sent over a telephone or other long line, it is essential that the impedance of the amplifier output be matched to that of the line if good quality is to be realized.

Most telephone lines are 500 ohms impedance. Therefore, it is standard practice to have the output impedance of microphone amplifiers 500 ohms.

As only low volume is allowed over the telephone lines, only a microphone amplifier is used at the remote-control station. If the volume was high, it would be very difficult, or impossible, to keep the program from disturbing the proper operation of other wires in the same cable.

There is usually a volume control on the microphone amplifier. Often a jack for a pair of headphones is provided so that the operator can monitor the program if more elaborate equipment is not available.

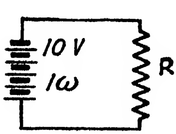


FIG. 286.—Circuit showing some of the features of impedance matching.

Impedance Matching.—Impedance matching is necessary for two reasons: (1) to avoid distortion and (2) to obtain maximum power output. Some of the facts about impedance matching can be illustrated by the following problem: Set up the circuit shown in Fig. 286 consisting of a 10-volt battery having an internal resistance of 1 ohm and a resistor R. The resistance of the battery is greater than is ordinarily found, but this value simplifies the mathematics. The problem is to determine the voltage across the resistor R. For the first example, let R be 1

ohm. The total resistance in the circuit will be 2 ohms and the total current $\frac{10}{2}$, or 5 amp. The voltage across the resistor will then be $I \times R$, 5×1, or 5 volts. For the next example, let R be 9 ohms. The total resistance in the circuit will be 10 ohms, and the current $\frac{10}{10}$, or 1 amp. The voltage across the resistor will be 9×1, or 9 volts. For the last example, let R equal 99 ohms. The total resistance will be 100 ohms, the current will be $\frac{10}{100}$, or $\frac{1}{10}$ amp., and the voltage across the resistor will be $\frac{99}{0.1}$, or 9.9 volts. An inspection of these answers will show that as the resistance of the load resistor becomes larger, in comparison with the internal resistance of the source of voltage, more of the generated voltage becomes available across the load where it can be used. Thus, in the example, when the load resistance was equal to the internal resistance of the battery, only one-half of the battery voltage appeared across the load. When the load resistance was increased to 9 ohms, 90 per cent of the voltage appeared across the load, and when the load was 99 ohms, 99 per cent of the voltage was usable. This same principle applies to the output of any electric device such as an oscillator, transmitter, microphone, or vacuum tube.

The input of any Class A tube does not use current and so there is no question of power output involved, because power always equals the current squared multiplied by the resistance. Therefore, when there is no current there can be no power. In circuits such as these, a maximum voltage is desired and that is obtained by having the load impedance as high as possible. For this reason, the step-up ratio of carbon microphone input transformers is made as high as possible and yet avoid distortion due to the distributed capacity. The relation between power and impedance matching will be brought out in another problem.

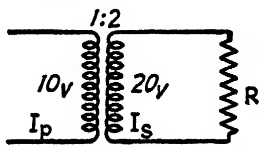


FIG. 287.—Circuit showing the effect of the load on the secondary on the primary impedance.

A transformer with a 2:1 ratio has a resistor R connected across the secondary, as shown in Fig. 287. The primary voltage is 10 volts, which will make the secondary 20 volts. For the first

example, let R be 20 ohms. The secondary current will then be $\frac{20 \text{ volts}}{20 \text{ ohms}}$, or 1 amp. The power developed in the secondary will be 20×1, or 20 watts. The power in the primary will be the same, if the losses in the transformer are neglected. Since the voltage in the primary is 10 volts, it will be necessary to have a current of 2 amp. to obtain 20 watts. The impedance of the primary circuit will then be $\frac{E}{I}$, $\frac{10}{2}$, or 5 ohms.

For the second problem, let R be 10 ohms. The secondary current will be $\frac{20}{10}$, or 2 amp. The power in the secondary will be 20×2, or 40 watts. This will require a current of $\frac{40}{10}$, or 4 amp., in the primary. The primary impedance will now be $\frac{10}{4}$, or $2\frac{1}{2}$ ohms.

An examination of the results of these two problems shows that the primary impedance is $\frac{1}{4}$ of the secondary load in each case. The square of the turn ratio is also $\frac{1}{4}$.

To give this relation a further rough check, let the turn ratio of the transformer be 1:3 and the load resistance R be 30 ohms. If the primary voltage remains 10 volts, the secondary voltage will now be 30 volts. The secondary current will be $\frac{30}{30}$, or 1 amp. The secondary power will be 30×1, or 30 watts. The current in the primary to obtain 30 watts would be $\frac{30}{10}$, or 3 amp. The primary impedance would be $\frac{10}{3}$, or $3\frac{1}{3}$ ohms. The square of the turn ratio is 1:9 in this case, and the ratio of the impedances is $3\frac{1}{3}$ to 30, or 1:9 also.

These problems give a rough check on the rule that the ratio of the impedance of the primary and secondary circuits of a transformer is the same as the square of the turn ratio. The rule enables the serviceman to determine the proper turn ratio for matching any two impedances. For example: To find the proper turn ratio for an output transformer to connect a pair of 6L6 tubes to an 8-ohm voice coil, the ratio of the impedances is found

first. The plate to plate (total primary) impedance required is 5,000 ohms. This information can be found in manufacturers' tube manuals. The impedance ratio is $\frac{5,000}{8}$, or 625:1. The turn ratio will be the square root of this ratio, or 25:1.

Notice that the actual number of turns on the coils has no bearing on the impedance ratio. However, the number of turns on the coils cannot be neglected. The necessity for a high primary impedance was discussed under "Transformer Characteristics" in Chap. VI, page 110.

All these problems have dealt with resistances. However, it is just as true that, if a capacitive or inductive reactance is placed across the secondary, it will act like a similar reactance across the primary whose value is the value of the reactance across the secondary multiplied by the impedance ratio. For example, the rather small buffer condenser across the secondary of a vibrator power transformer would have a fairly high reactance. However, since the primary is step-down from the secondary, the reflected impedance across the primary would be less—in other words the small condenser across the secondary has the same effect on the circuit as a much larger one across the primary would have. And so cost and space are saved. The same principle is used with the condensers used in condenser starting a-c motors.

There is another phase of the impedance-matching problem that it will be necessary to investigate. Returning to the problems with the 10-volt battery, the power developed across the resistor R when it is 1 ohm is I^2R, which becomes $5 \times 5 \times 1$, or 25 watts. When R is 9 ohms, the power is $1 \times 1 \times 9$, or 9 watts. When R is 99 ohms, the power is $0.1 \times 0.1 \times 99$, or 0.99 watts. It will be noticed that, as the resistance of the load becomes greater than the source, the percentage of the voltage of the source, which is available across the load, increases. This is the condition that is desirable when no power is required. When a maximum power is required, the best load value is entirely different. The examples given above partly show that for maximum power transfer the load impedance must equal the impedance of the source. The desirability of maximum power transfer exists only at two points in an amplifier. These are the output transformer and the input transformer to a Class

AB_2 or Class B stage where the grids draw current and therefore require power. But even in these instances maximum power is not the only desirable feature, for what is really wanted is a maximum power output with less than a noticeable amount of distortion, which usually means less than 4 per cent. For triodes this means that the proper load impedance is twice the plate impedance. For pentodes and beam-power tubes no rule can be given. The load impedance is chosen to keep the distortion within specified limits and at the same time realize as much power as possible. For the operation of relays, maximum power with no consideration of distortion is required. Therefore, for best results the impedance of the relay should be the same as the plate impedance.

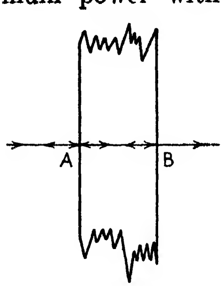


Fig. 288.—Diagram illustrating the effect of reflection on the output of a circuit.

The last phase of the impedance-matching problem can be most easily explained by referring to a similar phenomenon in relation to light which is more familiar to the average individual. Figure 288 shows a portion of a thick plate of glass. It is fairly common knowledge that two reflections are seen when looking into a plate-glass window. These reflections are often slightly displaced from each other and the total effect is like a blurred image. The fact that two reflections are obtained shows that all the light that strikes the plate glass at the surface *A* does not enter the glass, for if it did there would be no reflection from that surface. The second reflection from the surface *B* indicates that all the light that enters the glass from the front does not leave by the back but a portion of it is reflected toward the front. A part of this reflected light comes through the front surface *A* and a part of it is re-reflected by this surface. Again a portion of this re-reflected light passes out of the glass through the surface *B*, and a part of it is reflected again. All the reflections are caused by light passing from one substance to another of different density. In this case, it was from glass to air or air to glass.

To appreciate the full effect of these repeated reflections, the nature of the reflected beam should be taken into account. Light is a wave motion of exactly the same nature as radio and electrical current. It has frequency and wave length like radio waves.

The only difference between light and radio waves is that the light waves have a shorter wave length. Since the problem involves frequency, the matter of phase difference is important. If the wave length of the light reflected from the surface *B* has the proper wave length, and the glass is the proper thickness, the portion of the light re-reflected from the surface *A* will be in phase with the light entering at the surface *A*. Under these circumstances, the new and the reflected wave will add together and the light of this particular frequency will be reinforced. At a slightly different frequency, the re-reflected light will be 180 deg. out of phase with the incoming light. Under these circumstances, the new and the reflected wave will buck each other, and the light of that particular frequency getting through the surface *B* will be the difference between the two.

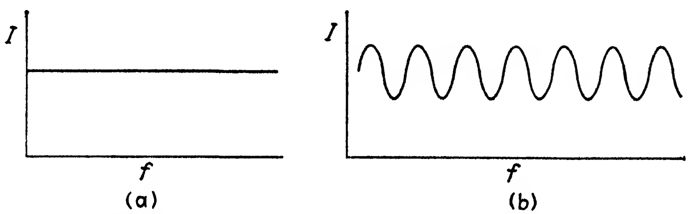


FIG. 289.—(*a*) Illustration of the current starting into a mismatched transformer. (*b*) Illustration of the current actually getting into a mismatched transformer.

Electrical current of various frequencies passing through a circuit behaves in exactly the same manner. Any change in the impedance of the circuit has the same effect as a change in density has on light. When the impedance of a circuit changes, a whole series of equally spaced frequencies in the band will be reinforced; a second series of frequencies that alternate with the first series will be lowered in volume.

This is illustrated in Fig. 289. If a steady value of current which varied in frequency such as is indicated in part (*a*) were to be fed into a mismatched transformer or into a voice coil mismatched with the output transformer, the value of the current actually getting into the transformer or voice coil would be as shown in part (*b*). Thus, if a current rich in harmonics is passed through a circuit with mismatched impedances, some of these frequencies will be reinforced and some of them will be attenuated. The resulting output, therefore, will not be like the

input. The degree of mismatch of the impedances determines the amount of distortion produced.

To summarize the whole impedance-matching problem: For the maximum voltage transfer, the impedance of the load should be as high as possible. To obtain the best transfer of power, the impedance of the source and the load should be equal. To avoid distortion, the impedances must be matched when current is involved.

The method of determining the total impedance of any grouping of speakers was discussed in Chap. I. When the calculated answer does not agree with any of the taps brought out on the output transformer, it is possible that the impedance between some pair of the taps not including the common might be useful. To determine the impedance between any two taps the following formula should be used

$$Z = Z_L\left(\sqrt{\frac{Z_h}{Z_L}} - 1\right)^2,$$

in which Z is the unknown impedance.

Z_h is the higher impedance terminal.

Z_L is the lower impedance terminal.

For example, in a transformer having 2-, 4-, 8-, 15-, and 500-ohm taps on the secondary, the impedance obtained by using the 4- and 8-ohm taps but not the common would be

$$\begin{aligned} Z &= 4(\sqrt{\tfrac{8}{4}} - 1)^2 = 4(\sqrt{2} - 1)^2 \\ &= 4(1.414 - 1)^2 = 4(0.414)^2 \\ &= 4 \times 0.171 = 0.684 \text{ ohm.} \end{aligned}$$

The impedance between the 8- and 15-ohm taps would be

$$\begin{aligned} Z &= 8(\sqrt{\tfrac{15}{8}} - 1)^2 = 8(\sqrt{1.875} - 1)^2 \\ &= 8(1.37 - 1)^2 = 8(.37)^2 \\ &= 8 \times .137 = 1.09 \text{ ohms.} \end{aligned}$$

Mixer Circuits.—When the program calls for the use of more than one microphone or for a microphone supplemented by a phonograph for sound effects, then the problem arises as to how to feed all the sources into one tube. Before the advent of high-gain amplifiers this was usually done by feeding each input into a transformer and then connecting the secondaries in parallel or parallel series or even in series across the grid-cathode circuit

of the first tube of the amplifier. The volume of each input was controlled by a constant-impedance volume control. The introduction of the high-gain amplifier and high-impedance microphones and phonograph pickups caused this system to be

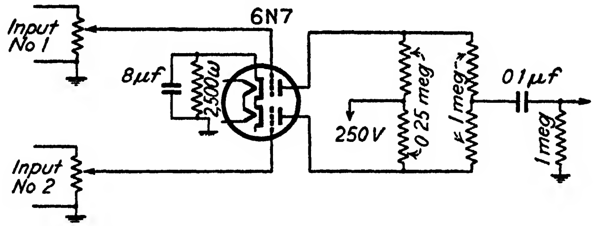


FIG 290.—Circuit diagram of an electronic mixer circuit.

discarded principally because of hum picked up by the transformers.

Modern mixer circuits are known as "electronic" mixers with each input applied to a different control grid. Often a twin triode is used, as shown in Fig. 290. This circuit does not

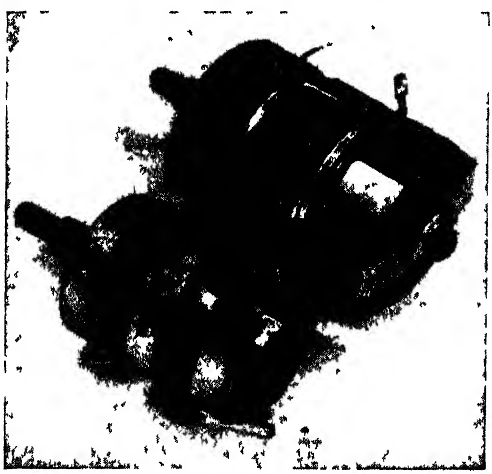


FIG. 291.—Constant-impedance *T*-pad controls.

require a transformer to combine the two outputs; nor does it require constant-impedance controls. It is therefore much cheaper to build than the transformer type of mixer. Since it uses fewer transformers than the transformer type, it is not so liable to give trouble from hum pickup. Furthermore, it

will have superior frequency characteristics because it contains fewer elements having reactance.

Additional mixer circuits will be found in the schematic diagrams of public-address amplifiers later in the chapter.

Constant-impedance Volume Controls.—Constant-impedance controls are of three varieties, the *T* pad, the π pad, and the *H* pad. Another pad known as the *L* pad has a constant impedance

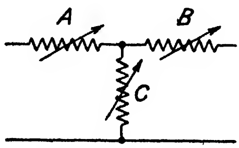


Fig. 292.—*T* pad.

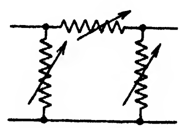


Fig. 293.—π pad.

from one side but not from the other. Figures 291 and 292 illustrate *T* pads. All three resistances are on the same shaft. As the shaft is rotated, resistances *A* and *B* increase in resistance while *C* decreases, or vice versa. The *IR* drop across the resistance *C* is the voltage that is fed into the output circuit. As *A* increases, *C* decreases, and the voltage across *C* will diminish; however, the total resistance in the input circuit will remain the same. Similarly, the combined effect of *B* and *C* in the output circuit maintains the resistance of this circuit constant. The

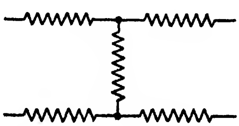


Fig. 294.—*H* pad.

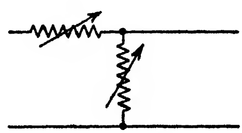


Fig. 295.—*L* pad.

constant-impedance controls should have the same impedance as the input circuits, all of which should have the same value. Under these conditions, the output will have the same impedance as any one of the input circuits.

Figure 293 shows the schematic diagram of a π pad. Its effect in the circuit is identical with that of the *T* pad. The *H* pad, shown schematically in Fig. 294, is usually fixed in value. It has the advantage of keeping both lines exactly alike. This feature helps to prevent hum and other unwanted pickup. The *L* pad is used where a constant impedance is not required on one side.

This control is often used between a phonograph pickup and the grid of a tube.

The T, π, and H pads can also be designed as fixed pads to connect from one impedance to a different one and present the proper impedance to each.

Volume Indicator.—A volume indicator may be a vacuum-tube voltmeter connected across the output or at some intermediate point. These are discussed more fully in Chap. IV. Sometimes it has a specially calibrated meter giving the volume in decibels. A decibel (abbreviated db) is a unit of volume. One decibel is approximately the smallest change in volume that the average ear can detect. This type of calibration is not essential. All that is necessary is to note the meter reading for satisfactory output and adjust the output to that point.

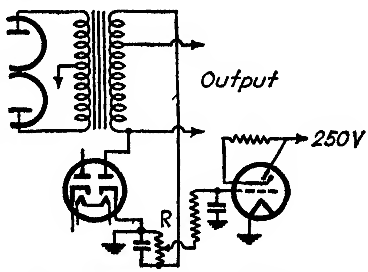


FIG. 296.—Circuit diagram of a tuning-indicator tube used as an output volume indicator.

Some volume indicators use a small cuprous oxide rectifier and a d-c milliammeter instead of a vacuum tube. The rectifier and the instrument are in series across the secondary of a transformer, which is usually of the step-down variety.

The schematic diagram of a circuit that uses a magic eye as an indicator of the volume is shown in Fig. 296. A portion of the output is rectified by a diode. The voltage developed across the load resistor R is applied to the control grid of the magic-eye tube. As the output volume increases, the voltage across the load resistor increases, and the eye closes. The potentiometer can be set so that the eye just closes when the desired volume is reached. By rehearsing a program beforehand, the readings of the potentiometer knob can be recorded for each portion of the program, and then all the operator has to do during the program is to adjust the volume to keep the eye just barely closed with the potentiometer on the proper setting. This eliminates much of the uncertainty of volume-control settings during the program.

Decibel.—In selecting a unit to express the gain or loss of volume in an audio circuit, it seemed reasonable and advan-

tageous to select as a unit a quantity such that, if the volume was increased or decreased by that amount, the change would be barely perceptible to the human ear. Upon investigation, it was discovered that the ear is much more sensitive to changes of volume at low levels than it is at high levels. For this reason, a logarithmic unit was chosen because it has the characteristic of increasing at a faster rate as it gets larger. The primary unit is the bel. The number of bels in a circuit is defined as $\log_{10} \frac{P_2}{P_1}$, in which $\frac{P_2}{P_1}$ is the ratio of the output power to the input power expressed in watts. This unit is too large for convenient use so the decibel or $\frac{1}{10}$ bel is used. The decibels in a circuit are $10 \log_{10} \frac{P_2}{P_1}$. Most of the manufacturers of public-address equipment have standardized on 0.006 watt, or 6 milliwatts, as the zero level; however, 0.012 watt, or 12 milliwatts, is used by at least one prominent manufacturer. Because of the two different standards, it is always necessary to know which zero level is used when comparing the rating of two amplifiers of different manufacturers. To find the decibel gain in an amplifier, divide the watts output by the watts input and then multiply the logarithm of this answer by 10. The output level can be expressed in decibels by dividing the output expressed in watts by 0.006, or 0.012, depending on the zero level used, and then multiplying the logarithm of this answer by 10. Output levels below 0.006 watt are expressed as negative decibels (−db). They are usually read as so many decibels "down." Thus the output of a ribbon microphone is spoken of as being "100 db down."

In 1939 a new unit was introduced which was more convenient to use and which most of the groups interested in the use of such a unit could agree on and thereby avoid the confusion caused by many standards. The new unit was given the name Vu. The reference or zero level was set at 1 milliwatt. The readings are + or − so many Vu, which are numerically equal to the number of decibels above or below the reference level.

Monitor Amplifier.—This is usually a one-stage audio amplifier connected at various points in different systems. Often it is tapped off the line between the microphone amplifier and the intermediate amplifier. It is used to supply energy to the loud-

speaker that the operator uses in following the program to detect noisy or faulty operation and to catch his cues for changes of microphone, volume, etc.

Installation and Operation of Public-address Systems.—In a permanent installation, all wires are run in rigid conduit and, in addition, are usually lead-covered or shielded with copper braid. This method of installation is used in order to prevent the pickup of unwanted noise from a-c wires, motors, telephone wires, etc. All chassis, conduit, and lead-sheath or copper-braid shielding should be bonded together and grounded at one spot. Avoid the use of more than one ground. The use of more than one ground often forms a large loop from one ground through the equipment and back to the other ground. Any flux due to a-c current or disturbance in some circuit cutting through this loop will generate a voltage in the loop that will cause noise in the output of the amplifiers. This difficulty is avoided by using only one ground, which makes the formation of such a loop impossible.

Input and output wires must not be run in the same conduit because of feedback and its resultant howl at the speaker.

One of the most difficult installations for public-address systems is that of a microphone and loud-speaker in the same room. The difficulty is particularly marked if the room has hard bare walls. The difficulty is this: The first sound that strikes the microphone goes through the amplifier and comes out of the loud-speaker. Owing to the bare walls, it is reflected back to the microphone and repeats this same performance. The result is a continual howl or whistle known as "audio feedback." Under these conditions, flat baffles usually cannot be used. The morning-glory-type horn or other types having directional properties can be used if placed properly. When the horns are properly placed, the sound will be directed away from the microphone in such a way that it will not be reflected back to it. Quite frequently the use of very high volume will cause feedback in spite of all that can be done. The placing of flags, banners, or drapes of any type around the walls will help to eliminate the feedback by absorbing the sound instead of reflecting it. When the program is to be speech only, the higher frequencies can be cut out. This will often stop the feedback.

For satisfactory results the microphone and the speakers, if they are in the same room, should be equally distant from

the audience. The reason is this: Sound travels about 1,090 ft. per second, and the electric impulses arrive almost instantaneously. Now, suppose a loud-speaker were placed toward the back of a large hall to increase the volume there. The sound of the speaker's voice uttering a word comes from the loud-speaker at exactly the same instant it is said, but the sound of the same word takes an appreciable time to travel through the air. It, therefore, is heard after the same word comes from the loud-speaker. The result is a kind of echo effect that ruins the clarity of the whole program. The usual procedure is to put the loud-speakers high over the speaker's head and a little in front of him.

Distribution of Sound.—Short wide horns throw the sound over a wide area relatively close to them. Long narrow horns throw the sound farther but over a smaller area. Choose the proper type of horn to suit the conditions.

In a system of medium or large size, an intercommunicating phone is installed so that an observer stationed in the audience can report to the operator on the volume level or other points in the transmission.

Some Other Details.—When lines over a few hundred feet in length are used, they begin to have sufficient capacity to affect the quality by absorbing the high notes. In order to compensate for this, the line is balanced. This is done by adding the proper amount of inductance, capacity, and resistance so that all frequencies will be transmitted equally well. This installation is a job for highly trained engineers because of the special and very costly equipment that must be used.

Sometimes cases arise where it is necessary to change back and forth from one program to another one of different volume and where it is desirable to equalize the two volumes in the output. This situation occurs, for instance, in changing from a microphone to an electric pickup. To adjust the volumes, an attenuation pad is put in the line furnishing higher volume. This pad should be so designed that it will not change the impedance of the line. For that reason, it cannot be a simple rheostat or potentiometer. The pad often has a circuit like the "*T* network" used for constant-impedance volume controls.

Transmission lines are always designed with low impedance because low-impedance lines do not pick up so much outside disturbance as do high-impedance lines.

Public-address-amplifier Circuits.—In choosing a circuit for a public-address amplifier, there are several points to bear in mind. In the first place, the amplifier should be powerful enough to carry the load, but, on the other hand, it should not be very much oversize. There are several reasons for this: (1) The initial cost and the operating expense of an oversize amplifier is higher. (2) If Class B amplifiers are used, the percentage of the distortion increases when they are working below full volume. (3) The larger amplifiers are more difficult to transport.

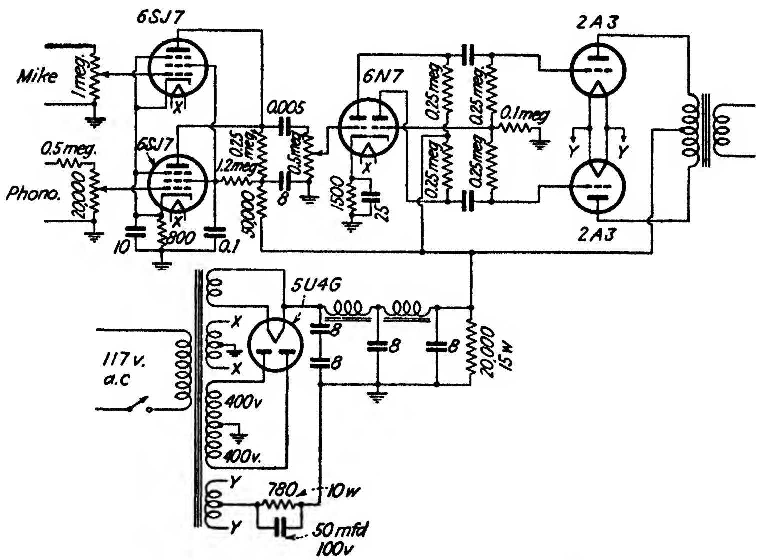


FIG. 297.—A 10-watt amplifier with a balanced phase inverter.

Class AB_1 amplifiers are very popular for a great majority of the public-address jobs that a serviceman encounters. They have the advantages of the Class B amplifiers in that they have high efficiency, use relatively small tubes, and require a minimum amount of power. They also have the added feature of lower distortion at low volume. In fact, a Class AB_1 amplifier acts as a Class A_1 amplifier on low volume.

The first amplifier to be discussed will be a Class AB_1 amplifier with an output of approximately 10 watts, which is sufficient for most of the indoor jobs encountered. The circuit is shown in Fig. 297. Provision is made for one high-impedance microphone

and a high-impedance phonograph. The half-megohm resistor in series with the phonograph pickup cuts its input voltage to make it more nearly the same as the microphone input. Note that two condensers in series are used for the filter input to take care of the voltage surges at this point. The use of push-pull triodes in the output stage reduces the distortion because triodes are much less critical to load variations with frequency than

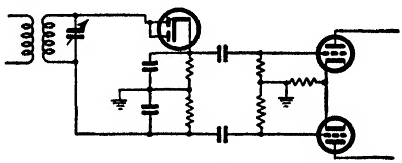


FIG. 298.—A method of obtaining phase inversion from the load resistor of a diode detector.

pentodes. A self-balancing phase-inverter circuit is used. The signal applied to the grid on the right-hand side of the 6N7 is the difference between the signals in the plate circuit of both sides of the tube. And, since part of the output of the right side appears across the 0.1-megohm resistor and is fed back into the grid, the circuit is degenerative and therefore has the stability of all degenerative circuits.

Other Phase-inverting Circuits.—There are several other methods that may be used to obtain phase inversion. Figure 298 illustrates a method of obtaining phase inversion in the diode circuit of the detector. This circuit depends on the fact that the pulsating voltage across the diode-load resistor will have opposite polarity at the two ends, therefore, if the center tap is grounded, two voltages of opposite polarity will be available for the grids of the push-pull stage.

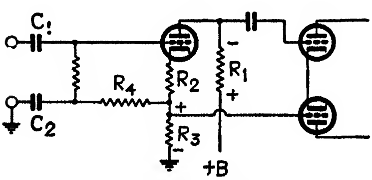


FIG. 299.—A phase-inversion circuit using only one tube.

Another method of obtaining phase inversion in an audio amplifier is shown in Fig. 299. The resistors R_1 and R_3 are the plate load resistors. Their combined value should be the proper value for the tube used. The resistor R_2 is the C bias resistor, which should have its normal value. The resistors R_3 and R_4 are effectively in parallel so far as the signal is concerned. The

total resistance of these two resistors in parallel added to R_2 should equal R_1. The condenser C_1 should be about 0.1 mf., but C_2 must be at least 5 mf. It may be an electrolytic condenser. The tube in this circuit will have a very low amplification factor—less than 2 in any case—but this should not be troublesome insofar as it is really taking the place of an input push-pull

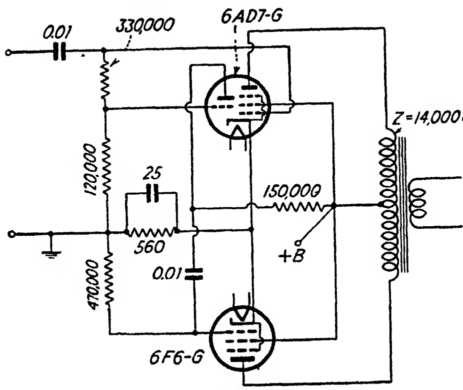


FIG. 300.—A phase-inverter circuit.

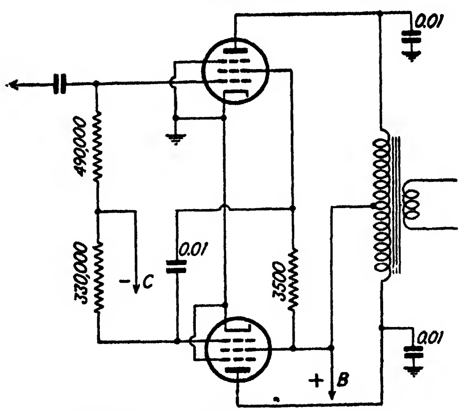


FIG. 301.—A phase-inverter circuit.

transformer and is performing its duty of splitting the signal without causing distortion as well as the best transformer could and doing it at much less cost.

An interesting adaptation of a common form of phase-inversion circuits is shown in Fig. 300. The triode portion of the 6AD7-G is used as the phase inverter. The pentode portion of the

6AD7-G and the 6F6G have identical characteristics and so work well in push-pull.

Phase inversion can also be obtained by feeding the signal voltage from the screen grid of one of the output tubes onto the control grid of the other. This is shown schematically in Fig. 301. A blocking condenser is used to block the screen-grid d-c voltage from the control grid. The balance of the two signal voltages on the grids is determined by the size of the screen-grid resistor.

Volume-expander Circuits.—When sound is recorded on a phonograph record, the maximum volume that can be recorded is limited by the thickness of the wall between the grooves. If the volume is allowed to become too high, the thickness of the groove wall is reduced to such an extent that the needle will break through when the record is used. The lowest volume that is practical to use is also limited by the needle scratch. It is, therefore, impossible to record symphonic orchestral music with all the range of volume levels that exist in the actual music.

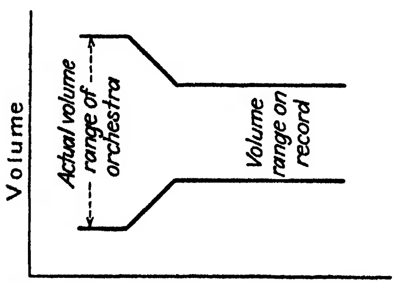


FIG. 302.—Diagram illustrating the effect of a compressor circuit.

Because of the mechanical limitations of the records, the signal from the microphone is passed through an amplifier having a compressor on it. This circuit compresses the volume range as illustrated in Fig. 302. It will be noted that the low volume is increased and the high volume lowered. Now, in order to reproduce the music with the volume as it originally was, it is necessary to feed the signal from the playback pickup into an amplifier having an expander on it. This circuit lowers the low volume still more and increases the high-volume passages. If the degree of expansion is the same as the compression used in making the recording, the result should be a faithful reproduction of the original volume changes. Both compression and expansion can be obtained in a number of ways. One of the best is by varying the amplification factor of a tube by varying its C bias. This operation requires a variable-mu grid for the same reason that one is required for a.v.c. In most cases the variable-mu

grid of a 6L7 or 1612 is used for this purpose while the signal is applied to the sharp cut-off grid. The 1612 tube is exactly like the 6L7 electrically; however, it is more ruggedly supported internally and, therefore, will be less likely to be microphonic. It is also possible to use any of the variable-mu tubes such as the 6SG7, 6SK7, 6S7, or 1851.

The only difference between the expander and compressor circuits is in the polarity of the voltage applied to the grid of the

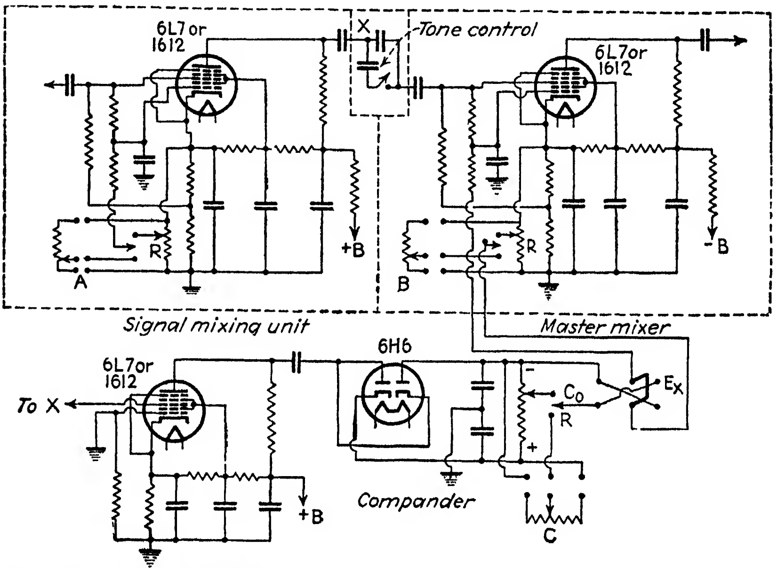


FIG. 303.—Circuit diagram of a compander circuit either for phonograph reproduction or with a microphone for a.v.c.

1612. Since the polarity can be reversed by a simple switch, it is possible to build a circuit that can be used either as an expander or as a compressor. Such a circuit is usually known as a "compander" circuit. The word "compander" is made up of parts of the two words "expander" and "compressor." The schematic diagram of such a circuit is shown in Fig. 303. The second 6L7 provides the expansion or compression. The voltage used on its grid is obtained by rectifying part of the input signal after it has been amplified. A 6H6 diode is used in a voltage doubler rectifier circuit to rectify the amplifier signal. The output of the rectifier is applied to the volume control which

is used to control the amount of expansion or compression that is obtained. For any setting of the expansion control the value of the voltage applied to the grid will depend on the size of the signal being fed into the stage. For expansion, the stronger the signal gets the more voltage will be produced. Since this is connected so as to buck out the steady negative bias on the tube, the actual bias will be lowered and the amplification factor of the tube will be raised. For compression, the rectified voltage adds to the C bias and raises it as the signal increases. It is perfectly possible to increase the compression to such a degree that the louder the signal gets the softer the output will become and very loud sounds will be cut off entirely.

In the circuit shown in Fig. 303 any number of signal-mixing units up to four, identical with the one shown, may be connected to the point X. The volume of each unit can be regulated by its individual control. The over-all volume of the whole amplifier is controlled by the potentiometer in the master-mixer circuit. When the d.p.d.t. switch in the compander circuit is in the E_x position the circuit operates as an expander. When the d.p.d.t. switch in the compander circuit is thrown to the C_o position, it reverses the voltage supplied to the 6L7 or 1612 tube. The circuit now is a compressor of the volume changes. When used with a microphone input, this circuit has several advantages: (1) It compensates to some extent the changes in volume caused by the speaker changing his distance from the microphone. (2) It can be set so that any sudden loud noise will not start the system howling.

Remote Volume Controls.—The schematic diagram of remote controls is also shown in Fig. 303 at A, B, and C. It is possible to use these controls with about 100 ft. of cable on them without feeding hum into the signal circuits because they are not in the signal circuits but operate on the C bias of the tube and so carry direct current only. These circuits are very convenient because they allow the operator to sit out in the audience and hear the program just the way they do.

Phonograph Amplifiers.—A compact amplifier that will reproduce phonograph records with very excellent quality is shown in Fig. 304. The input is arranged for a low-impedance pickup but the substitution of a half-megohm grid leak for the input transformer would be all that is necessary to fit it for a

high-impedance pickup. The pickup would be connected across the grid leak. The output will be about 4 watts, which should be sufficient for any installation that would not require a high-powered amplifier. The actual volume of sound that can be obtained from the amplifier depends fully as much on the efficiency of the speaker as on the wattage rating of the amplifier.

A 25-watt Public-address Amplifier.—The schematic circuit diagram of a high-powered Class AB1 amplifier is shown in

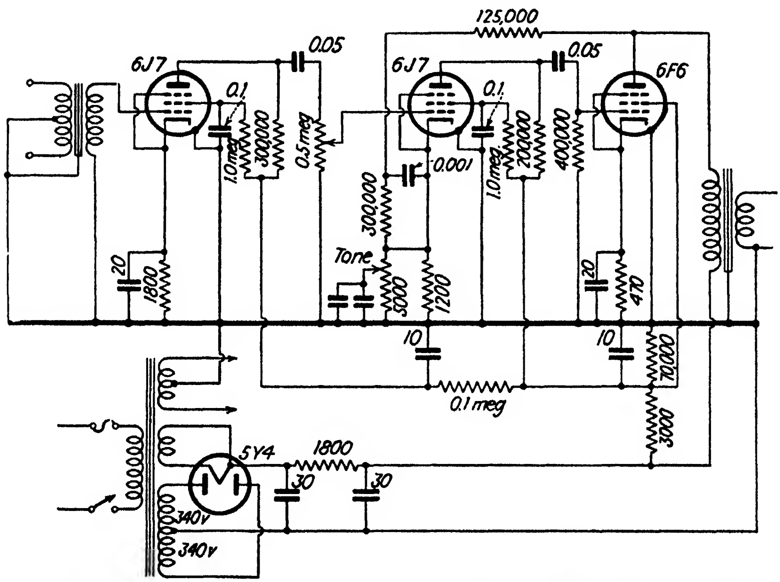


FIG. 304.—The RCA phonograph and recording amplifier M1-12700. (*Courtesy of RCA Manufacturing Co., Inc.*)

Fig. 305. The output of two microphones and a crystal phonograph pickup can be mixed in the input circuits. The output is 25 watts undistorted or 35 watts with less than 5 per cent distortion. The quality will depend largely on the speaker and output transformer and on the accuracy of the impedance match between them. A ½-megohm tone control in series with an 0.03-mf. condenser controls the h-f response. The 3-megohm tone control across the 0.001-mf. condenser provides wide control of the frequencies below 100 cycles. A third or tertiary winding on the output transformer furnishes inverse-feedback voltage. This method of obtaining inverse feedback keeps the resistance

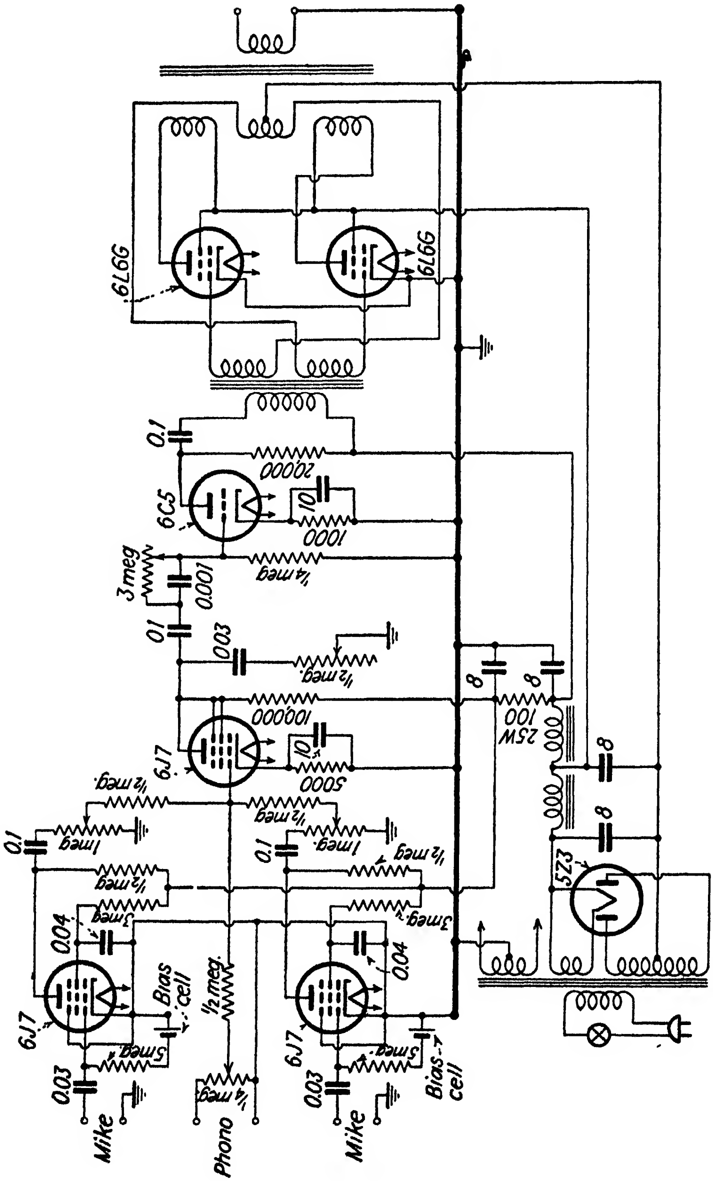


FIG. 305.—Circuit diagram of a Class AB1 amplifier.

in the grid circuits of the tubes low. For this reason this method can be used on amplifiers in which grid current flows.

It will be necessary to shield the grid and plate leads of the first three tubes including the resistors in the grid leads.

REVIEW QUESTIONS

15-1. Show a block diagram of the parts of a public-address system.

15-2. Name at least four types of microphones.

15-3. Which microphones are useful outdoors?

15-4. Under what circumstances will crystal microphones fail to work?

15-5. Describe the construction and operation of a two-button carbon microphone.

15-6. What are the desirable and undesirable features of carbon microphones?

15-7. Show a diagram of the circuits for connecting a carbon microphone to the grid of a tube.

15-8. What care and maintenance should a carbon microphone have?

15-9. Describe the construction and operation of a condenser microphone.

15-10. What are the desirable and undesirable features of a condenser microphone?

15-11. What care and maintenance should a condenser microphone have?

15-12. Describe the construction and operation of a ribbon microphone.

15-13. What are the desirable and undesirable features of a ribbon microphone?

15-14. What care and maintenance should a ribbon microphone have?

15-15. Describe the construction and operation of a dynamic microphone.

15-16. What are the desirable and undesirable features of a dynamic microphone?

15-17. What care and maintenance should a dynamic microphone have?

15-18. What is meant by a nondirectional microphone?

15-19. What is meant by a unidirectional microphone?

15-20. Give two reasons why impedance matching is important.

15-21. What relation exists between the turn ratio and the impedance ratio of a transformer?

15-22. Show a diagram of a circuit for mixing two microphone inputs.

15-23. Show the circuit and explain the operation of a constant-impedance *T* pad.

15-24. Show a circuit of a π pad.

15-25. What is a decibel?

15-26. Give the formula for the gain in decibels when the input and output power are known.

15-27. What precautions should be taken when the microphone and the loud-speakers of a public-address system are used in the same room? What type of speakers should be used under these conditions?

15-28. For what conditions are short wide horns used? Long slim horns?

15-29. Show a diagram of a two-tube phase-inverting circuit.

15-30. Show a diagram of a single-tube phase inverter (twin tube not included).

15-31. Of what value is an expander circuit?

15-32. Of what use is a compressor circuit?

15-33. Show a diagram of an expander circuit.

15-34. (*a*) Show a circuit of a remote volume control. (*b*) Why is this circuit free from hum and noise pickup?

CHAPTER XVI

THE BUSINESS SIDE OF RADIO SERVICING

This chapter is included with the hope that it will aid the serviceman in giving more efficient service and in selling that service in a manner which will enable him to build up and maintain a satisfactory income.

The radio serviceman must be not only a technician but a salesman. He must be able to repair radio sets, to sell his services, and to maintain a volume of business sufficient to ensure him an adequate income. Too frequently the best servicemen are very poor business managers and keep records insufficient to show whether or not the business is profitable.

There may be many reasons why servicemen frequently do not keep accurate records, the more common being: (1) They do not have the time to devote to office records. (2) They do not look upon such records as being of great importance. (3) Their training, consequently their interest, lies more deeply in the technical end of the business. However, there are certain essentials of the financial part of the business that are necessary if it is to succeed.

Operating a business without fairly accurate records generally leads to nowhere in particular. In other words, work should be planned and the plan made to work. There is also the problem of keeping informed of activities in the field, improvements, changes in equipment, etc. This can best be done through subscription to a selected list of publications, technical books, and affiliation with service associations. These items must be added to the cost of doing business. A serviceman should be paid for his knowledge and his ability to apply that knowledge.

The most important thing to bear in mind at all times is to establish good will and create opportunities for additional calls from old customers. The most certain way to lose the prospect of a second call is dishonesty of any kind. Overcharging or charging for parts and services that are not provided is almost certain to be discovered. When this happens, not only is the

owner of the set lost as a customer but all his friends and relatives will also be lost. Conversely, a satisfied customer is one of the very best advertisements that can be found. Endeavor at all times to look at the job in hand from the customer's point of view. It is important that the customer should get his money's worth and, more important, that he realize it. It is often wise to refuse to repair an extremely old set or a very cheap one with the loss of some possible profit, because these sets usually break down in a short time unless extensive and costly repairs are made. The proper procedure under these circumstances is to point out to the customer the fact that he is wasting his money trying to repair the set, and try to sell him a better set. You will gain a booster who may send you several jobs which, if handled properly, will provide many more channels through which jobs may come to you. Strive to build up and maintain a reputation for doing superior work and supplying reliable parts at reasonable prices. If a job will not be a credit to you, do not take it, or, if you have already taken it, return it without charge.

The serviceman often works in the home of the customer and often under the critical eye of the owner of the set. It is, therefore, necessary to think of the impression that the visit will make on the customer. In this connection, the following suggestions are offered:

Have an adequate set of tools and have them in some kind of container, arranged so they can be found easily. Incidentally, if a particular place is provided for each tool, it is very easy to see that none of the tools are left behind..

Carry a piece of canvas, oilcloth, or some heavy cotton cloth to spread down to work on. This will save soiling rugs or burning them with hot solder, etc., and makes it very easy to clean up any scraps of insulation, wire, etc. It is a good plan to have the customer watch as you test the tubes. When a bad one is discovered, remove it from the checker and insert a new one without altering any of the controls. In this way, the customer can be convinced of the honesty of your statement that the tube needs replacement. Your very apparent honesty in this matter increases the customer's confidence in you, much to your advantage.

In wet weather, always wear rubbers or some outer covering over your shoes and be sure to remove them before entering

the house. This may seem like a small detail, but it is one that the owner is certain to notice, particularly so if you forget it and track in mud and dirt on newly finished floors. No second opportunity to repeat the mistake will be provided, that is certain.

When a set has been taken to the shop and repaired, a telephone call should be made to determine when it would be convenient to have the set returned. It certainly would be unfortunate to attempt to install a chassis during a bridge party or an afternoon tea. A week or ten days after the set has been installed, a telephone call should be made to ascertain if the customer is completely satisfied.

Be businesslike during your call. That does not mean that you should be brusque or curt, but "stick to business." Have a definite procedure. Go to the set, test the tubes, make a set analysis if necessary, quickly decide whether to make the repair in the home or to take the set to the shop. Do what is necessary, get your fee, and leave. Act as if you had some other work to do. The customer is apt to think that if this is the only job you have to do you may be so glad to get it that you will do it at a cut rate. The less time you are in the home, the better the owner will like it; for he will look upon your visit as a necessary but an unwelcome intrusion.

Don't knock competitors. If someone has made mistakes in servicing a receiver, just say that it was in very bad shape and allow the owner to draw his own conclusions.

If you wish to be classed with professional men, you must look as well as act like a professional man. Keep your clothes clean and pressed. When installing antennas, wear coveralls and gloves. Wear gloves on the roof so that your hands will be in shape to do the inside work. The workman who enters a home wearing a suit with a pressing long overdue, carrying battered test and tool kits in grimy hands, is immediately classed as an odd-jobs man, certainly not as a member of a profession. Under these conditions, a serviceman has no right to object to being paid at the odd-job man's scale of wages.

If there is any unusual delay in returning the set, telephone the customer and explain the delay before he becomes disturbed enough to call you. If the difficulty is hard to locate, a frank statement of the facts is best. Then when the set is returned, if a moderate charge is made, the customer is sure to be an ardent

"booster" of your ability, which is worth many times the extra dollar or two that you might have charged him.

The departure from the home after making a repair can be speeded up by using some kind of holder for the hot soldering iron. A holder can be constructed by wrapping asbestos paper, such as heating-equipment installers use around hot-air pipes, around a piece of $1\frac{1}{4}$-in. iron pipe and then protecting the paper with a piece of thin tin or sheet iron.

Don't be afraid to give a little free service for the sake of its advertising value. Check up the antenna, ground connections, and lead-in. Often a new lead-in strip costing a few cents will make a vast improvement in the operation of the set. The slight cost in that case would be well spent for advertising. Possibly the lead-in and ground wires run along the baseboard and have been installed very carelessly. Straighten them out and make a workmanlike job of the installation. It usually takes very little time and little or no material, but the good-will value is great.

The judicious use of some furniture polish on the cabinet after the set is installed is another item that will gain favorable comment; however, it is best to ascertain the owner's preference for a highly polished or a dull finish before attempting this job. Be sure to use a polish that will not necessitate the airing of the house after your departure.

If possible, have a midget set to leave where a set has to be taken to the shop. Many people are ardent followers of some program and dislike exceedingly to miss it. The opportunity to sell the midget for a "second set" when the larger set is returned should not be ignored.

Have some kind of filing system for all the articles you find in magazines and other literature concerning the remedy of the ills of particular sets. Then, when the occasion to use this information comes, it can be readily found. One very satisfactory method is to use a set of fiber folders in which to file miscellaneous pamphlets, diagrams, and notes. All material in magazines is left in them, and they are filed in a box or drawer in chronological order. A single 3 by 5 card index is kept of both files. In this way, time is saved, for there is only one place to look for information. Blank index cards can be purchased, or they can be made easily by gluing tabs on 3 by 5 cards.

The author's own pet scheme in filing information is to put all the circuit diagrams under the head of "Circuit Diagrams" and then list the various sets in alphabetical order. Articles on other subjects are grouped under such heads as "Hum," "Loudspeaker," "Meters," "Oscillators," "Tone Control," or "Automatic Volume Control." A sample card is shown in Fig. 306. In this way, articles on almost any subject related to radio service work can be located in a very short time. The file can be kept up to date by listing the material in a magazine as soon as it has been read. This usually takes not over 10 min. and is time well spent.

RCA-Victor	Circuit Diagram
16X and 16X-13	*Radio Today*, Jan. 41, p. 38
BT-42 Battery Radio	*Radio Craft*, Feb. 41, p. 476
VHR-307 Chassis RC 555	*Radio Craft*, May 41, p. 682

FIG. 306.

Many servicemen find it advantageous to keep a card file of all their customers. These cards show what work was done on the set, the date, and the charges. If the number and the type of the tubes in the set have been recorded, the serviceman is able to take along just the right tubes in making a repair call. This often saves making another trip to supply them.

Tack your business card on the inside of the cabinet. Don't put it on the bottom where it will be covered with dust and dirt or where the owner will have to crawl inside the cabinet to read it. This is always looked upon as a guarantee of good work, for no one will place his name on a piece of work that is not a credit to him. It will also enable the owner to recall your name and telephone number in case of future difficulty.

Side Lines.—There are many side lines that the serviceman can carry which will add materially to his income. Many people neglect to buy such items as extra electric-light bulbs and fuses and are very glad to have lamp cords or convenience outlet caps replaced. Flatiron cords are often used long after they should be discarded because the owner forgets to purchase a new one. It requires little sales ability to suggest to the customer that you can replace a frayed lamp cord or broken cap which you notice, and this often causes him to bring out other similar jobs.

The subject of electric phonographs and the pleasure of being able to listen to favorite tunes at will can often be introduced with the subsequent sale of a phonograph pickup and oscillator.

Effective Advertising.—As in any other business, so in radio service, advertising cannot be overlooked. Billboards, streetcars, magazines, newspapers, and radio programs, all indicate that tremendous amounts are being spent for advertising, all of which must return big dividends on the investment.

It is a trite saying that no business can exist today without advertising. But with the limited means usually available to a serviceman, it is essential that he consider the various kinds of advertising very carefully to be sure that he will get returns for his outlay. Without question, the first expenditure should be for a sign on his shop stating his name and business. Signs can be obtained that are painted on canvas and arranged to be fastened to the door of an automobile by snap fasteners that will not mar the appearance of the car when the sign is removed.

The important thing to guard against is investing too heavily and too unwisely in advertising. A very careful program should be planned. Study conditions in the locality and then work out a logical plan that fits the need and the funds available. Bear in mind that immediate results are rarely obtained. To prove a real success advertising must be continued over an extended period of time. Persistence pays dividends.

Advertising must attract the eye and register in the mind of the individual. The impression may come from certain color combinations, some novel display of merchandise, an appeal to his vanity, or his curiosity, and certainly every individual can be appealed to through his pocketbook.

Try to be original in your ideas. With a little thought many good advertisements can be developed.

Do not overlook your old customers in the advertising campaign. Repeat business is desirable and can be had through honest, prompt, and dependable service.

Several manufacturers of receivers and tubes provide a wide selection of advertising material for the use of the serviceman. In choosing from this material, the serviceman should consider the following points:

1. The type of customers who will receive the material. Pictures of pretty girls on calendars and blotters are standard,

but for an appeal to housewives a picture of children at play or similar subjects is much better. Stuffing handbills in the mailboxes of apartment houses is a waste of time and is subject to prosecution. They seldom get farther than the lobby and often create ill will.

2. The kind of advertising material other firms have presented to the same people. Advertising material to have any value should not be a duplicate of, or similar to, the material put out by some other company.

3. Length of time the material will be effective. Many types of material—packets of matches, radio programs, etc.—are discarded very quickly. Results from this type of material should be immediate. Advertising of this sort should stress the idea of having the receiver repaired *now*. Blotters, calendars, etc., are before the customer for a longer period and should carry a message of the permanency of your business, a willingness to stand behind your work, and your availability on short notice at any time.

4. The advertising value of lending a public-address system to church and charity organizations for picnics, etc., with your name, business, and address prominently displayed on it should be considered.

Telephone Selling.—Profitable business and good will can be built up by proper use of the telephone. Always keep in mind that telephone conversation differs very little from actual contact with individuals. The mere fact that a few feet or a few miles of wire intervene does not alter the situation. You are still conversing with a prospect. Learn to speak pleasantly, naturally, friendly, and specifically.

Never keep a customer waiting for any length of time. And above all, be sure to understand the customer's wants. Be truthful in your promises and prompt in carrying them out.

A good plan to follow is to make an analysis of calls that have brought in business, and calls wherein you have lost a customer. Do not be afraid to lay some of the blame on yourself when it is apparent that the blame lies with you.

Do not be too anxious to quote prices. It is presumed that you know your business, that you know values of service and merchandise, and that at the proper time prices can be intelligently discussed.

Always be ready to advise your customer of special values that you may have to offer, never, however, running off a long list of merchandise which is bound to become tiring and boresome.

Do not attempt to build up a large telephone business unless you are prepared to handle it and remember it is vitally important that calls receive intelligent attention. In short, it is expensive to attempt to build up a telephone business and then not have someone to answer the calls or give satisfactory information. Remember the telephone is an excellent medium for keeping in touch with old customers.

Bookkeeping.—This section is not intended to be a text on bookkeeping, but merely an attempt to show the serviceman how to keep records from which information essential to the successful conduct of his business may be obtained. The outline as presented here has been limited to the simplest kind of bookkeeping and requires a minimum of time. Owing to the ever-increasing demands of both the Federal and state governments for records of business activities, it is imperative that complete and accurate records be kept. These may be simple or they may be elaborate and complex, depending upon the size of the business and the temperament of the individual. Income taxes must be paid, and state sales taxes assessed and paid on reports filed with the proper tax officials. Therefore, accurate records of inventories, purchases, sales, services, and other items of income and expense should be available for compiling these reports at stated intervals. Service records should also be kept on all repair jobs, providing complete information as to the customer's name, his address, telephone number, make of radio, trouble found, how corrected, cost of materials and service, and the price charged. From such records valuable data can be assembled in spare time.

The Daily Record Card (Fig. 307) is divided so as to provide space on the left side for Receipts and on the right side for Disbursements. Separate columns are provided on the Receipts side for Receivable and Received and on the Disbursement side for Payable and Paid. The Receivable column should include all work finished on that day but not paid for on that day. The Payable column should include all items bought on that day but not paid for. When payment is made on an item, the amount will have to be subtracted from the Receivable or Payable

column and added to the Received or Paid column, as the case may be. On this card all items of receipts and expenditures are listed for the day. All items paid are entered on the Disbursement side of the card. The first item (Overhead) on each day's card is obtained from the previous month's average on The Monthly Expense Memo (Fig. 311). Initial payments on equipment purchased are likewise entered here, and all subse-

DAILY RECORD

DAY Saturday DATE Mar. 21, 1942

Description	Receipts		Description	Disbursements	
	Receivable	Received		Payable	Paid
J. Wilson		2.75	Overhead	5.10	
H. Brown		3.25	Gasoline		1.25
F. C. Long Co.	1.75		Ash Radio Co.	1.30	
G. Allen		1.75	Radio Corp.		.73
M. Owens		10.00			
1. Today's total	1.75	17.75		6.40	1.98
2. Previous total	18.00	23.75		19.92	14.43
3. Total to date	19.75	41.50		26.32	16.41

FIG. 307.

quent payments on the day on which they are paid. All items received are entered on the Receipts side of the card. If an extensive charge business is done, separate ledger records should be kept, a card being opened up for each customer on which all charges to and receipts from this customer are posted. When cash is received on these accounts, the amount should also be entered on the Receipts side of the Daily Record Card (Fig. 307) on the day on which it is received. However, it is recommended that this type of business be kept to an absolute minimum. It requires time and money to make collections.

At the end of the day the Daily Record Card is added and the totals are entered on line 1 at the bottom of the card. Line 2 carries the totals for the preceding days of the week. Lines 1 and 2 are now added and the total entered on line 3. These totals are then carried forward to line 2 of the new Daily Record Card for the next day, a new Daily Record Card being used each day.

WEEKLY RECORD

MONTH March, 1942

Date	Receipts			Disbursements		
	Receivable	Description	Received	Payable	Description	Paid
2-7	28.75		57.60	13 25		25 46
9-14	21.62		42.25	19.60		18.75
16-21	~~19.75~~ 11.75	Rec'd of F. C. Long 8.00	~~41 50~~ 49.50	~~26.32~~ 22.12	Ash Radio Co. 4.20	~~16.41~~ 20.61
23-31	12.65		51 00	11 50		22.00
	74.77	Totals for month	200 35 74 77	66.47	Totals for month	86.82 66.47
		Revenue for month	275.12		Expenditures for month	153.29

FIG. 308.

A glance at this Daily Record Card for the day shows a total income of \$1.75 and \$17.75, or \$19.50, against total expenses of \$6.40 plus \$1.98, or \$8.38, the gross profit for the day being the difference between \$19.50 and \$8.38, or \$11.12. Likewise, the same comparison for the week may be made by analyzing the figures in line 3.

At the end of the week the totals of line 3 of the card for that day are entered on the Weekly Record Card. Should changes occur in Receivables or Payables during the following week, these changes may be made as shown for the third week's entries

on Fig. 308, \$8.00 received from F. C. Long is added to \$41.50 cash received, making a total of \$49.50, and is also deducted from \$19.75 Receivable, making a new total of \$11.75 Receivable. After totals for the month are entered, further changes may be made in similar manner.

MONTHLY RECORD				
Month	Revenue	Disbursements	Gross Profit	
			Month	Year to Date
January	227.43	121.15	106.28	106.28
February	331.40	172.20	159.20	265.48
March	275.12	153.29	121.83	387.31

Fig. 309.

After these adjustments have been made, the total revenue and total disbursements should be entered on the Monthly Record Card (Fig. 309), which shows revenue for the month, disbursements for the month, gross profit for the month, and total gross profit for the year to date.

The Inventory Record Card is shown in Fig. 310. To start a record of this kind, a physical inventory should be taken. The cost price of the merchandise should be used in computing the value of the inventory. This amount should be inserted in column headed Inventory and, if carried into Increase or Decrease column, simplifies the figuring of increase or decrease at the end of the month, as illustrated.

In Fig. 311, a Monthly Expense Memo card, it will be noted that provision is made for listing all items of direct expense, such as salary, light and heat, rent, telephone, and advertising,

INVENTORY RECORD				
Date	Purchased	Sold	Inventory	Increase or decrease
Feb. 28 Mar. 2–7	 20 00	 22.00	112.00 110.00	112 00
Mar. 9–15	12.00	11.00	111.00	
Mar. 17–23	9.50	20.00	100.50	
Mar. 25–31	17.00	14.50	113.00	113.00

Fig. 310.

one line being provided for each month of the year. The total expenses for the month, divided by the number of working days in that month, provide the first item on each Daily Record Card during the following month.

At the end of the year, this Monthly Record Card (Fig. 309) can be easily totaled, giving total receipts for the year, total disbursements for the year. By adding to this figure the amount of the inventory, net worth can be determined. Adjustments should be made for any unexpired or unpaid payables. The unpaid payables would include insurance, taxes, depreciation on equipment, etc.

Some means should be provided for the filing of all invoices received. It is recommended that an alphabetical file be used, filing all invoices from each creditor separately. Should there be a desire to elaborate on this, a separate file could be used for filing all Paid Invoices. This would provide information as to

MONTHLY EXPENSE MEMO

Month	Light, heat	Rent	Tele-phone	Adver-tising	Salary	Miscel-laneous	Daily Average
January	14.00	19.00	4.00	12.00	75.00		4.75
February	13.50	19.00	4.00	7.10	75.00	12.50	5.10
March	12.00	19.00	4.00	6.00	75.00	15.10	5.46

FIG. 311.

how much has been paid each creditor and how much is owed each creditor.

Changes may be necessary in this plan to suit the individual. However, this may easily be done due to its simplicity, without affecting its general efficiency

APPENDIX

ABBREVIATIONS FREQUENTLY USED

A	filament or heater circuit; a class of amplifiers; area of core
A'	a class of amplifiers
AB	same as A'
a-c	alternating current
a-f	audio frequency
A.F.C.	audio-frequency choke
A.G C.	automatic gain control
AM	amplitude-modulated
amp.	ampere
A.V.C.	automatic volume control
A. W. G.	American wire gauge, same as Brown & Sharpe
B	plate circuit; a class of amplifiers
B. & S.	Brown & Sharpe wire gauge
C	grid circuit, capacity, class of amplifiers
cat. ray	cathode-ray oscillograph
cir. mils	circular mils
C. W.	continuous wave
C_1, C_2, C_3	designate several condensers in a circuit
D	diode
db	decibel
d-c	direct current
d.c.c.	double cotton covered
det.	detector
d.p.d.t.	double-pole double-throw
d.p.s.t.	double-pole single-throw
d.s.c.	double silk covered
E	voltage, enamel covered
E_B	plate battery voltage
E_C	grid-bias battery voltage
E_f.	filament or heater voltage
E_g	d-c grid voltage
e_g	a-c grid voltage
e.m.f.	electromotive force; voltage
E_p	d-c plate voltage; primary voltage
e_p	signal voltage in the plate circuit
E_s	secondary voltage
e_s	signal voltage
F	vacuum-tube filament
f	frequency

fld.	field
FM	frequency-modulated
G	ground
gm	transconductance
Gnd	ground
H	vacuum-tube heater, magnetic field strength
h.	henry
I	current
I.C.W.	interrupted continuous wave
i-f	intermediate frequency
i_g	alternating grid current
I_p	direct plate current
i_p	alternating plate current
kc.	kilocycle
L	inductance
L. S.	loud-speaker
M	mutual inductance; coupling
ma.	milliampere
mc.	megacycle
meg.	megohm
Ω	megohm
mf., mfd., or μf	microfarad
μh	microhenry
mike	microphone
mil	one-thousandth of an inch
mmf., mmfd., or μμf	micromicrofarad
μw	microwatt
N	north pole
N.S.C.	noise-suppression circuit
ω	ohm
osc.	oscillator
P	vacuum-tube plate
pot.	potentiometer
pri.	primary
Q	ratio of the inductive reactance of a coil to its resistance
Q.A.V.C.	quiet automatic volume control
R	resistance
r.c.	rubber covered
r-f	radio frequency
R.F.C.	radio frequency choke
r.m.s.	root-mean-square
R_p	plate load resistance
r_p	internal plate resistance
r_1, r_2, r_3	designate several resistors in a circuit
S	vacuum-tube shell, south pole
s.c.c.	single cotton covered
s.c.e.	single cotton enameled covered
S_{scg}	vacuum-tube screen grid

sec.	secondary
spkr	speaker
s. p. s. t.	single-pole single-throw
s.s.c.	single silk covered
s.s.e.	single silk enameled covered
T. C.	top cap
T. M.	tuning meter
T.R.F.	tuned radio frequency
V	volts, velocity of light
V. C.	volume control, voice coil
vol. cont.	volume control
V. T.	vacuum tube
V_1, V_2, V_3	designate several vacuum tubes in a circuit
Vu	volume unit
W	watt
X_c	capacitive reactance
X_L	inductive reactance
Y	a method of connecting three phase transformers, same as star connection
Z	impedance

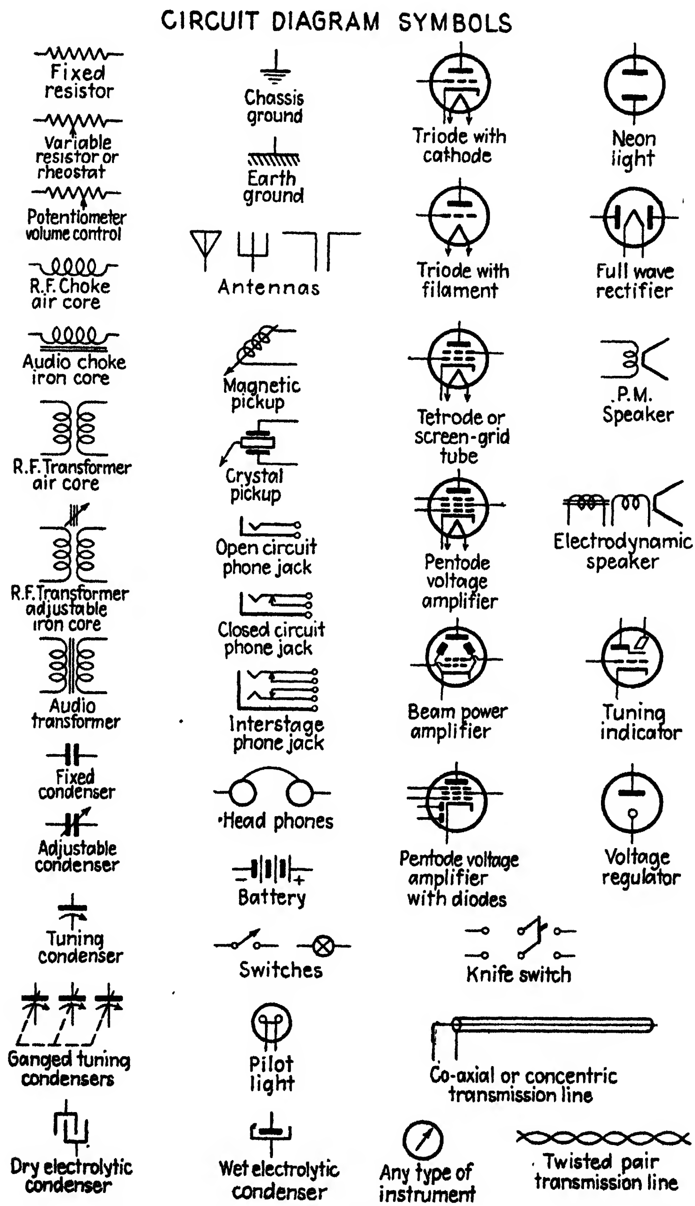

CIRCUIT DIAGRAM SYMBOLS
Fixed resistor
Variable resistor or rheostat
Potentiometer volume control
R.F. Choke air core
Audio choke iron core
R.F. Transformer air core
R.F. Transformer adjustable iron core
Audio transformer
Fixed condenser
Adjustable condenser
Tuning condenser
Ganged tuning condensers
Dry electrolytic condenser
Chassis ground
Earth ground
Antennas
Magnetic pickup
Crystal pickup
Open circuit phone jack
Closed circuit phone jack
Interstage phone jack
Head phones
Battery
Switches
Pilot light
Wet electrolytic condenser
Triode with cathode
Triode with filament
Tetrode or screen-grid tube
Pentode voltage amplifier
Beam power amplifier
Pentode voltage amplifier with diodes
Knife switch
Co-axial or concentric transmission line
Any type of instrument
Neon light
Full wave rectifier
P.M. Speaker
Electrodynamic speaker
Tuning indicator
Voltage regulator
Twisted pair transmission line

Fig. 312.

GREEK ALPHABET AND SYMBOLS

	Capital	Small	Used to Designate
Alpha	A	α	Angles
Beta	B	β	Angles
Gamma	Γ	γ	
Delta	Δ	δ or ∂	(Capital) a small increase; three-phase connection
Epsilon	E	ϵ	(Small) 2.718; (capital) voltage
Zeta	Z	ζ	(Capital) impedance
Eta	H	η	
Theta	Θ	θ	Angular phase displacement
Iota	I	ι	Current
Kappa	K	κ	
Lambda	Λ	λ	(Small) wave length
Mu	M	μ	(Small) prefix micro, amplification factor
Nu	N	ν	
Xi	Ξ	ξ	
Omicron	O	o	
Pi	Π	π	(Small) stands for 3.1416
Rho	P	ρ	
Sigma	Σ	σ or s	
Tau	T	τ	
Upsilon	Υ	υ	
Phi	Φ	ϕ	Phase
Chi	X	χ	
Psi	Ψ	ψ	
Omega	Ω	ω	(Capital) megohm; (small) ohm

Copper-wire Table

B. & S. gauge No.	Circular-mil area	Turns per linear inch*				Turns per square inch*			Ohms per 1,000 ft. 25º C.	Current-carrying capacity at 1,500 cir. mils per ampere†
		Enamel	S.s.c.	D.s.c. or s.c.c.	D.c.c.	S.c.c.	Enamel s.c.c.	D.c.c.		
1	82,690	.....	.....	.....	....	....	....	....	0.1264	55.7
2	66,370	.....	....	....	....	....	.....	.....	0.1593	44.1
3	52,640	....	....	....	....	......	....	......	0.2009	35.0
4	41,740	.....	.....	.....	....	....	....	....	0.2533	27.7
5	33,100	.....	....	....	....			.	0.3195	22.0
6	26,250	.....	...	.....	....	......	....	......	0.4028	17.5
7	20,820	.....	.....	.....	....	....	....	......	0.5080	13.8
8	16,510	7.6	.....	7.4	7.1	....	....	....	0.6405	11.0
9	13,090	8.6	....	8.2	7.8	....	....	....	0.8077	8.7
10	10,380	9.6	...	9.3	8.9	87.5	84.8	80.0	1.018	6.9
11	8,234	10.7	....	10.3	9.8	110	105	97.5	1.284	5.5
12	6,530	12.0	.....	11.5	10.9	136	131	121	1.619	4.4
13	5,178	13.5	.....	12.8	12.0	170	162	150	2.042	3.5
14	4,107	15.0	.....	14.2	13.3	211	198	183	2.575	2.7
15	3,257	16.8	.....	15.8	14.7	262	250	223	3.247	2.2
16	2,583	18.9	18.9	17.9	16.4	321	306	271	4.094	1.7
17	2,048	21.2	21.2	19.9	18.1	397	372	329	5.163	1.3
18	1,624	23.6	23.6	22.0	19.8	493	454	399	6.510	1.1
19	1,288	26.4	26.4	24.4	21.8	592	553	479	8.210	0.86
20	1,022	29.4	29.4	27.0	23.8	775	725	625	10.35	0.68
21	810.1	33.1	32.7	29.8	26.0	940	895	754	13.05	0.54
22	642.4	37.0	36.5	34.1	30.0	1,150	1,070	910	16.46	0.43
23	509.5	41.3	40.6	37.6	31.6	1,400	1,300	1,080	20.76	0.34
24	404.0	46.3	45.3	41.5	35.6	1,700	1,570	1,260	26.17	0.27
25	320.4	51.7	50.4	45.6	38.6	2,060	1,910	1,510	33.00	0.21
26	254.1	58.0	55.6	50.2	41.8	2,500	2,300	1,750	41.62	0.17
27	201.5	64.9	61.5	55.0	45.0	3,030	2,780	2,020	52.48	0.13
28	159.8	72.7	68.6	60.2	48.5	3,670	3,350	2,310	66.17	0.11
29	126.7	81.6	74.8	65.4	51.8	4,300	3,900	2,700	83.44	0.084
30	100.5	90.5	83.3	71.5	55.5	5,040	4,660	3,020	105.2	0.067
31	79.70	101.0	92.0	77.5	59.2	5,920	5,280	....	132.7	0.053
32	63.21	113.0	101.0	83.6	62.6	7,060	6,250	....	167.3	0.042
33	50.13	127.0	110.0	90.3	66.3	8,120	7,360	....	211.0	0.033
34	39.75	143.0	120.0	97.0	70.0	9,600	8,310	......	266.0	0.026
35	31.52	158.0	132.0	104.0	73.5	10,900	8,700	....	335.0	0.021
36	25.00	175.0	143.0	111.0	77.0	12,200	10,700	....	423.0	0.017
37	19.83	198.0	154.0	118.0	80.3	....	....	....	533.4	0.013
38	15.72	224.0	166.0	126.0	83.6	....	....	....	672.6	0.010
39	12.47	248.0	181.0	133.0	86.6	....	....	....	848.1	0.008
40	9.88	282.0	194.0	140.0	89.7	....	....	....	1069	0.006

* The figures given are approximate only, since the thickness of the insulation varies with different manufacturers.

† The current-carrying capacity at 1,000 cir. mils per ampere is equal to the circular-mil area (column 2) divided by 1,000.

Frequency of Piano Keys

Based on current musical pitch, A = 440 cycles per second.
Physical pitch, A = 426.6 cycles per second.
International pitch, A = 435 cycles per second.

F	Note on piano	F	Note on piano	F	Note on piano	F	Note on piano
27.50	Lowest A	123.47	B	523.25	C	2349.30	D
30.87	B	130.81	C	587.33	D	2637.00	E
32.70	C	146.83	D	659.26	E	2793.80	F
36.71	D	164.81	E	698.46	F	3136.00	G
41.20	E	174.61	F	783.99	G	3520.00	A
43.65	F	196.00	G	880.00	A	3951.10	B
49.00	G	220.00	A	987.79	B	4186.00	C
55.00	A	246.94	B	1046.50	C		(last
61.74	B	261.63	Middle C	1174.70	D		note on
65.41	C	293.66	D	1318.50	E		the
73.42	D	329.63	E	1396.90	F		piano)
82.41	E	349.23	F	1568.00	G		
87.31	F	392.00	G	1760.00	A		
98.00	G	440.00	A	1975.50	B		
110.00	A	493.88	B	2023.00	C		

IMPORTANT CONSTANTS AND FORMULAS

$\pi = 3.1416$

1 meter = 39.37 in.

746 watts = 1 hp.

Speed of light: 300,000,000 meters per second

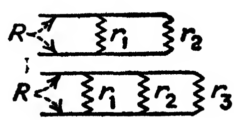
Speed of sound: 1,090 ft. per second, approximately

Ohm's law:

$$E = IR; \qquad I = \frac{E}{R}; \qquad R = \frac{E}{I};$$

$$R = \frac{r_1 \times r_2}{r_1 + r_2}$$

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$$



Inductive reactance: $X_L = 2\pi fL$

Capacitive reactance: $X_c = \dfrac{1}{2\pi fC}$

Impedance:

$$Z = \sqrt{R^2 + X_L^2}; \quad Z = \sqrt{R^2 + X_c^2}; \quad Z = \sqrt{R^2 + (X_L + X_c)^2}$$

For power transformers:

$$\frac{N}{E} = \frac{100,000,000}{BAf4.44}; \qquad A = \frac{\sqrt{W_p}}{5.58}; \qquad I_p = \frac{Wp}{E_p \times 0.9}$$

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{V}{\lambda}; \qquad \lambda = 1,885\sqrt{LC} = \frac{V}{f}$$

Power:

$$W = I^2R = EI = \frac{E^2}{R} \text{ for d-c.}$$

DRILL AND TAP SIZES

Screw size	Threads	Tap drill		Drill for clearance
		Iron	Brass	
0	80	56	56	52
1	70	53	53	48
2	56	47	47	42
2	64	49	49	42
3	50	45	46	37
3	60	44	45	37
4	32	40	41	32
4	36	40	41	32
4	48	39	41	32
5	40	36	37	30
5	50	35	36	30
6	32	31	32	27
6	40	31	32	27
6	48	31	31	27
7	40	29	30	22
8	32	27	28	18
8	40	26	27	18
10	24	21	22	9
10	32	18	19	9
10	40	17	18	9
10	48	15	17	9
12	24	13	15	1
12	30	11	13	1
12	32	10	12	1
12	40	8	10	1
13	26	8	9	¼
14	20	7	8	¼
14	24	6	8	¼
14	32	3	4	¼
¼	20	6	9	17/64

RESISTANCE-COUPLED AMPLIFIER CHART

C_d = screen-grid by-pass condenser and R_d = screen-grid resistor

C = blocking condenser (μf)
C_k = cathode by-pass condenser (μf)
E_{bb} = plate-supply voltage (volts)
E_o = voltage output (peak volts)
R_k = cathode resistor (ohms)
R_g = grid resistor (megohms)
R_b = plate resistor (megohms)
V.G. = voltage gain

2A6, 2B7: see Types 75 and 6B8 in this chart. 6A6,* 6B6-G, 6B7: see Types 6N7, 75, and 6B8 in this chart. 6B8, 6B8-G, 6B7, 2B7

E_{bb}[1]	90									180									300								
R_b	0.1			0.25			0.5			0.1			0.25			0.5			0.1			0.25			0.5		
R_g[2]	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2
R_d	0.37	0.5	0.6	1.18	1.1	1.35	2.6	2.8	2.9	0.44	0.5	0.6	1.18	1.2	1.5	2.6	2.8	3	0.5	0.55	0.6	1.2	1.2	1.5	2.7	2.9	3.4
R_k	2,000	2,200	2,000	3,500	3,500	3,500	5,000	6,000	6,200	1,000	1,200	1,200	1,900	2,100	2,200	3,300	3,500	3,500	950	1,100	900	1,500	1,600	1,800	2,400	2,500	2,800
C_d	0.07	0.07	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.08	0.08	0.07	0.05	0.06	0.05	0.04	0.04	0.04	0.09	0.09	0.08	0.06	0.06	0.08	0.05	0.05	0.05
C_k	3	3	2.8	1.9	2.1	1.9	1.5	1.55	1.5	4.4	4.4	4	2.7	3.2	3	2.1	2	2.2	4.6	5	4.8	3.2	3.5	4	2.5	2.3	2.8
C	0.03	0.01	0.006	0.008	0.007	0.003	0.004	0.003	0.003	0.02	0.015	0.008	0.01	0.007	0.003	0.006	0.003	0.002	0.025	0.015	0.009	0.015	0.008	0.004	0.006	0.008	0.0025
E_o[3]	19	28	29	26	33	32	22	29	27	30	52	53	39	55	53	47	55	53	60	89	80	70	100	95	80	120	90
V.G.[4]	24	33	37	43	55	65	63	85	100	30	41	46	55	69	83	81	115	116	36	47	54	64	79	100	96	150	145

6C5, 6C5-G, (6C6, 6J7, 6J7-G, 6W7-G, 57 as triodes)

E_{bb}[1]	90									180									300								
R_b	0.05			0.1			0.25			0.05			0.1			0.25			0.05			0.1			0.25		
R_g[2]	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1
R_k	2,800	3,400	3,800	4,800	6,400	7,500	11,400	14,500	17,300	2,200	2,700	3,100	3,900	5,300	6,200	9,500	12,300	14,700	2,100	2,600	3,100	3,800	5,300	6,000	9,600	12,300	14,000
C_k	2	1.62	1.3	1.12	0.84	0.66	0.52	0.4	0.33	2.2	2.1	1.85	1.7	1.25	1.2	0.74	0.55	0.47	3.16	2.3	2.2	1.7	1.3	1.17	0.9	0.59	0.37
C	0.06	0.026	0.01	0.026	0.01	0.005	0.01	0.006	0.004	0.056	0.03	0.015	0.035	0.015	0.008	0.015	0.008	0.004	0.075	0.04	0.015	0.035	0.015	0.008	0.015	0.008	0.008
E_o[3]	14	17	20	16	22	23	18	23	26	34	45	54	41	54	56	44	52	59	57	70	83	65	84	88	73	85	97
V.G.[4]	9	9	10	10	11	12	12	12	13	10	11	11	12	12	13	13	13	13	11	11	12	12	13	13	13	14	14

6C6, see Types 6J7 and 6C5 in this chart. 6C8-G (one triode unit)†

E_{bb}[1]	90									180									300								
R_b	0.1			0.25			0.5			0.1			0.25			0.5			0.1			0.25			0.5		
R_g[2]	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2
R_k	3,040	3,700	4,520	6,770	7,870	8,830	12,400	15,000	16,500	2,420	3,080	3,560	5,170	6,560	7,550	9,840	12,500	15,600	2,120	2,840	3,250	4,750	6,100	7,100	9,000	11,500	14,800
C_k	2.34	1.48	1.29	0.95	0.81	0.69	0.51	0.43	0.38	2.84	1.84	1.6	1.25	0.95	0.85	0.66	0.5	0.44	3.93	2.01	1.79	1.29	0.96	0.77	0.67	0.48	0.37
C	0.028	0.0115	0.006	0.011	0.0065	0.0035	0.006	0.0035	0.0015	0.028	0.012	0.0065	0.012	0.007	0.0035	0.007	0.004	0.0015	0.037	0.013	0.007	0.013	0.0065	0.004	0.007	0.004	0.002
E_o[3]	13	17	19	15	19	21	16	20	25	30	40	45	35	45	50	38	44	51	55	73	80	64	80	90	67	83	96
V.G.[4]	18	20	21	21	23	23	22	24	24	20	22	23	24	25	26	25	26	26	22	23	25	26	26	27	27	27	28

6F5, 6F5-G, 6SF5

E_{bb}[1]	90									180									300								
R_b	0.1			0.25			0.5			0.1			0.25			0.5			0.1			0.25			0.5		
R_g[2]	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2
R_k	4,400	4,800	5,000	8,000	8,800	9,000	12,200	13,500	14,700	1,800	2,000	2,200	3,500	4,100	4,500	6,100	6,900	7,700	1,300	1,600	1,700	2,600	3,200	3,500	4,500	5,400	6,100
C_k	2.5	2.1	1.8	1.33	1.18	0.9	0.76	0.67	0.58	4.4	3.3	2.9	2.3	1.8	1.7	1.3	0.9	0.83	5	3.7	3.2	2.5	2.1	2	1.5	1.3	0.93
C	0.02	0.01	0.005	0.01	0.006	0.003	0.005	0.003	0.0015	0.025	0.015	0.006	0.01	0.006	0.004	0.006	0.003	0.0015	0.025	0.01	0.006	0.01	0.007	0.004	0.006	0.004	0.003
E_o[3]	4	5	6	6	7	10	8	10	12	16	23	25	21	26	32	24	33	37	33	43	48	41	54	63	50	62	70
V.G.[4]	29[5]	34[5]	35[5]	39[5]	43[5]	44	43	46	48	37	44	46	48	53	57	53	63	66	42	49	52	56	63	67	65	70	70

6F8-G (one triode unit)†, 6J5, 6J5-G

E_{bb}[1]	90									180									300								
R_b	0.05			0.1			0.25			0.05			0.1			0.25			0.05			0.1			0.25		
R_g[2]	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1
R_k	1,650	2,070	2,380	3,470	3,940	4,420	7,360	9,760	10,690	1,190	1,490	1,740	2,330	2,830	3,230	5,560	7,000	8,110	1,020	1,270	1,500	1,900	2,440	2,700	4,590	5,770	6,950
C_k	2.80	2.66	1.95	1.85	1.29	1.0	0.73	0.55	0.47	3.27	2.86	2.06	2.19	1.35	1.15	0.81	0.62	0.5	3.56	2.96	2.15	2.31	1.42	1.2	0.87	0.64	0.54
C	0.06	0.029	0.012	0.035	0.012	0.007	0.0135	0.007	0.004	0.06	0.032	0.0115	0.038	0.012	0.006	0.013	0.007	0.004	0.06	0.034	0.012	0.035	0.0125	0.0065	0.013	0.0075	0.004
E_o[3]	11	14	17	12	17	19	14	18	20	24	30	36	26	34	38	28	36	40	41	51	60	43	56	64	46	57	64
V.G.[4]	11	12	13	13	13	13	13	13	13	13	13	13	14	14	14	14	14	14	13	14	14	14	14	14	14	14	14

RESISTANCE-COUPLED AMPLIFIER CHART (Continued)

6J5, 6J5-G, see Type 6F5-G in this chart. 6J7, 6J7-G, 6C6, 6W7-G, 57 (as pentodes), see also Type 6C5 in this chart

E_{bb}	90									180									300								
R_c	0.1			0.25			0.5			0.1			0.25			0.5			0.1			0.25			0.5		
R_g	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2
R_s	0.37	0.44	0.44	1.1	1.18	1.4	2.18	2.6	2.7	0.44	0.5	0.5	1.1	1.18	1.4	2.45	2.5	2.7	0.44	0.5	0.58	1.18	1.18	1.45	2.45	2.9	2.95
R_k	1,300	1,100	1,300	2,300	2,500	3,600	4,700	5,500	5,500	1,000	750	500	1,300	1,600	2,000	2,300	2,100	3,300	500	450	600	1,100	1,200	1,300	1,700	2,300	2,300
C_s	0.05	0.06	0.06	0.03	0.03	0.025	0.02	0.05	0.02	0.08	0.05	0.05	0.04	0.04	0.04	0.03	0.025	0.02	0.07	0.07	0.06	0.04	0.04	0.05	0.04	0.04	0.04
C_k	5.2	5.3	4.8	3.7	3.2	2.5	2.3	2	2	6.5	6.7	6.7	5.5	4.3	3.8	2.2	2.5	2.8	8.5	8.3	8	5.5	5.4	5.8	4.2	4.1	4
C	0.02	0.01	0.006	0.008	0.005	0.003	0.006	0.0025	0.0015	0.02	0.01	0.006	0.008	0.005	0.0035	0.006	0.0025	0.0015	0.02	0.01	0.006	0.008	0.005	0.005	0.005	0.003	0.0015
E_o	17	22	33	23	22	33	23	20	27	42	52	[illegible]	41	60	65	45	55	60	55	81	96	81	104	110	75	97	[illegible]
V.G.	41	55	66	70	85	93	93	130	140	51	69	[illegible]	93	118	140	125	165	165	61	82	94	104	140	185	161	350	[illegible]

6L5-G

E_{bb}	90									180									300								
R_c	0.05			0.1			0.25			0.05			0.1			0.25			0.05			0.1			0.25		
R_g	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1
R_k	2,120	2,600	2,900	3,510	4,620	5,200	8,050	10,300	12,100	1,810	2,240	2,660	3,180	4,800	4,750	7,100	9,250	10,950	1,740	2,180	2,600	3,070	4,140	4,700	6,900	9,100	10,750
C_k	2.3	1.98	1.65	1.36	1.08	1	0.61	0.40	0.42	2.9	2.2	1.8	1.46	1.1	1	0.7	0.54	0.40	2.91	2.18	1.82	1.64	1.4	0.81	0.57	0.40	0.4
C	0.05	0.03	0.014	0.03	0.015	0.0085	0.0125	0.0085	0.0058	0.06	0.03	0.014	0.03	0.0145	0.010	0.014	0.009	0.0055	0.06	0.032	0.015	0.032	0.014	0.0075	0.013	0.0075	0.006
E_o	14	18	21	16	22	23	18	22	24	32	41	46	36	46	50	32	46	52	56	68	79	69	79	89	84	89	88
V.G.	9.2*	10*	11*	11*	12*	12*	12*	12*	12*	10*	11*	12*	12*	12*	12*	12*	12*	13*	11*	12*	12*	12*	13*	13*	13*	13*	13*

6N7,* 6N7-G,* 6A6, 53

E_{bb}	90									180									300								
R_c	0.1			0.25			0.5			0.1			0.25			0.5			0.1			0.25			0.5		
R_g	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2
R_k	1,900	2,250	2,500	4,050	4,950	5,400	7,050	8,500	9,650	1,200	1,700	1,950	2,950	3,300	4,200	5,200	6,400	7,400	1,150	1,500	1,750	2,850	3,400	4,000	4,850	6,100	7,150
C	0.025	0.01	0.006	0.01	0.006	0.003	0.006	0.003	0.0015	0.03	0.015	0.007	0.015	0.007	0.0035	0.007	0.0035	0.002	0.03	0.015	0.007	0.015	0.0065	0.003	0.0065	0.003	0.0015
E_o	13	19	20	16	20	24	18	23	26	25	46	50	40	50	57	44	54	61	60	83	86	75	87	100	76	94	104
V.G.	16	18	20	20	22	23	22	23	23	19	21	22	26	24	24	24	25	25	20	22	23	23	24	24	23	24	24

6Q7, 6Q7-G

E_{bb}	90									180									300								
R_c	0.1			0.25			0.5			0.1			0.25			0.5			0.1			0.25			0.5		
R_g	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2
R_k	4,000	4,200	4,300	7,200	7,600	8,000	11,600	12,300	13,700	1,600	1,900	2,100	3,400	4,000	4,500	6,800	7,100	7,900	1,200	1,500	1,700	2,600	3,000	3,600	4,600	5,500	6,200
C_k	2.07	1.7	1.5	1.17	1.2	0.9	0.72	0.6	0.45	3	2.5	2.3	1.6	1.3	1.05	0.96	0.75	0.62	4.4	2.6	3.05	2.4	1.66	1.45	1.2	0.9	0.9
C	0.02	0.01	0.005	0.01	0.005	0.003	0.006	0.003	0.0015	0.02	0.01	0.005	0.01	0.005	0.003	0.006	0.003	0.002	0.03	0.015	0.007	0.015	0.007	0.004	0.007	0.004	0.002
E_o	5	8	9	8	11	13	9	12	17	19	26	29	25	31	37	30	36	41	35	52	53	43	52	62	47	60	66
V.G.	23*	28*	29*	31*	32	33	31	33	37	28	33	35	36	38	40	38	40	41	34	39	40	42	45	46	45	46	47

6R7, 6R7-G

E_{bb}	90									180									300								
R_c	0.05			0.1			0.25			0.05			0.1			0.25			0.05			0.1			0.25		
R_g	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1
R_k	2,300	2,600	2,900	3,800	4,400	5,000	7,600	9,800	11,300	1,700	2,300	2,500	3,000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,300	2,000	[illegible]	[illegible]	[illegible]	4,400	[illegible]	[illegible]	10,000
C_k	2	1.7	1.27	[illegible]	[illegible]	0.77	0.54	0.42	0.33	[illegible]	1.9	[illegible]	1.3	[illegible]	0.8	[illegible]	[illegible]	[illegible]	2.6	[illegible]	1.6	[illegible]	1.1	1	[illegible]	0.5	[illegible]
C	0.05	0.03	0.01	[illegible]	0.01	0.005	0.015	0.007	0.003	0.05	0.03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.055	[illegible]	0.015	[illegible]	[illegible]	[illegible]	0.015	[illegible]	[illegible]
E_o	14	18	20	15	19	21	15	18	21	31	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47	[illegible]	62	71	[illegible]	[illegible]	71	54	[illegible]	[illegible]
V.G.	8	9	10	10	10	11	10	11	11	9	9	10	[illegible]	[illegible]	10	[illegible]	[illegible]	11	9	9	10	10	10	10	10	11	11

Resistance-coupled Amplifier Chart (Continued)

6S7, 6S7-G

E_b	90									180									300								
R_p	0.1			0.25			0.5			0.1			0.25			0.5			0.1			0.25			0.5		
R_g	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2
R_s	0.19	0.66	0.7	1.5	1.6	1.7	3.3	3.5	3.7	0.58	0.69	0.71	1.6	1.8	1.8	3.2	3.5	3.8	0.5	0.57	0.71	1.7	1.9	2.1	3.6	3.9	4.1
R_k	870	900	910	1,440	1,530	1,600	2,620	2,800	3,000	530	540	540	860	890	900	1,410	1,530	1,560	430	440	440	630	660	700	1,000	1,080	1,120
C_s	0.065	0.061	0.057	0.044	0.044	0.043	0.029	0.03	0.031	0.073	0.07	0.068	0.06	0.044	0.046	0.041	0.037	0.031	0.077	0.071	0.071	0.058	0.057	0.055	0.04	0.041	0.042
C_k	5.1	5	4.55	3.35	3.32	3.23	2.04	1.95	1.92	7.2	6.9	6.6	4.6	4.7	4.4	3.5	3	2.9	8.5	8	8	6	5.8	5.2	4.1	3.9	3.8
C	0.018	0.01	0.007	0.007	0.0055	0.004	0.004	0.0026	0.0024	0.017	0.01	0.0062	0.0071	0.005	0.0037	0.0041	0.003	0.0024	0.0167	0.01	0.0066	0.0071	0.005	0.0036	0.0037	0.0030	0.0026
E_o	15	21	28	14	18	19	12	15	16	33	43	48	33	40	44	30	38	42	57	75	82	54	66	76	52	60	73
V.G.	35	47	54	56	66	77	70	84	94	47	66	75	79	103	113	109	134	147	57	78	90	98	122	136	139	162	174

6SC7*

E_b	90									180									300								
R_p	0.1			0.25			0.5			0.1			0.25			0.5			0.1			0.25			0.5		
R_g	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.25	0.25	0.5	1	0.5	1	2
R_k	1,850	1,900	2,050	3,400	3,750	3,900	5,800	6,300	7,480	960	1,070	1,220	1,650	2,150	2,400	3,000	3,420	3,890	750	930	1,040	1,400	1,680	1,840	2,330	2,980	3,280
C	0.025	0.012	0.0065	0.011	0.006	0.003	0.005	0.003	0.0015	0.031	0.012	0.0065	0.011	0.006	0.003	0.006	0.003	0.002	0.033	0.014	0.007	0.012	0.006	0.003	0.006	0.003	0.002
E_o	4.1	5.9	6.9	6.2	8.6	10	7.4	10	12	17	24	27	21	28	32	24	32	36	35	50	54	45	55	64	50	62	72
V.G.	13	22	25	26	30	33	31	33	36	25	29	33	35	39	41	40	43	45	29	34	36	39	42	45	45	48	49

6SF5 see Type 6F5 in this chart. 6SJ7

E_b	90									180									300								
R_p	0.1			0.25			0.5			0.1			0.25			0.5			0.1			0.25			0.5		
R_g	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2
R_s	0.29	0.30	0.31	0.69	0.92	0.82	1.5	1.7	1.9	0.29	0.31	0.37	0.83	0.84	0.94	1.85	2.2	2.4	0.35	0.37	0.47	0.80	1.10	1.18	2.0	2.2	2.5
R_k	830	880	1,000	1,650	1,700	1,800	3,600	3,800	4,050	760	860	800	1,650	1,000	1,100	2,000	2,180	2,410	500	530	590	850	860	910	1,300	1,410	1,530
C_s	0.09	0.085	0.075	0.06	0.045	0.04	0.045	0.03	0.028	0.10	0.09	0.09	0.06	0.06	0.07	0.06	0.04	0.035	0.10	0.09	0.09	0.07	0.06	0.06	0.06	0.05	0.04
C_k	8.8	7.4	6.6	5	4.5	4	2.4	2.4	2.35	9.1	8	7.8	6.8	6.6	6.1	4.0	3.8	3.6	11.6	10.9	9.9	8.5	7.4	6.9	6	5.8	5.2
C	0.02	0.016	0.007	0.012	0.005	0.003	0.003	0.002	0.0015	0.019	0.015	0.007	0.001	0.004	0.003	0.003	0.002	0.0015	0.019	0.016	0.007	0.011	0.004	0.003	0.004	0.002	0.0015
E_o	18	29	28	16	18	22	18	22	24	49	60	62	38	47	54	37	44	54	72	96	101	79	88	98	64	79	89
V.G.	41	66	70	75	93	104	91	119	139	55	82	91	109	131	161	151	192	208	67	98	104	139	167	185	209	236	263

6SQ7 see Type 75 in this chart. 6T7-G

E_b	90									180									300								
R_p	0.1			0.25			0.5			0.1			0.25			0.5			0.1			0.25			0.5		
R_g	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2
R_k	4,350	4,750	5,050	7,500	8,300	9,000	12,500	14,300	15,500	2,420	2,830	3,080	4,410	5,220	5,920	7,250	9,440	10,850	1,950	2,400	2,640	3,760	4,580	5,220	6,570	8,200	9,000
C_k	1.8	1.5	1.43	1.12	1	0.88	0.67	0.6	0.54	2.65	2.25	2	1.5	1.25	1.11	0.91	0.74	0.6	2.85	2.55	2.25	1.57	1.35	1.23	1.02	0.82	0.7
C	0.023	0.012	0.007	0.012	0.0075	0.005	0.0065	0.0045	0.0035	0.023	0.0135	0.008	0.012	0.008	0.005	0.007	0.0045	0.0035	0.0245	0.0135	0.008	0.012	0.0075	0.005	0.008	0.0055	0.004
E_o	5.6	7.8	8.5	7.7	10	12	9.4	12	13	21	29	32	27	34	39	31	39	43	44	58	64	57	69	80	62	77	86
V.G.	20	24	25	28	30	32	31	33	34	24	28	31	34	36	38	38	41	41	27	32	33	37	40	41	42	43	44

6W7-G see Types 6J7 and 6C5 in this chart. 6Z7-G*

E_b	90									180									300								
R_p	0.1			0.25			0.5			0.1			0.25			0.5			0.1			0.25			0.5		
R_g	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2
R_k	1,490	1,700	1,930	3,000	3,300	3,670	5,300	6,050	6,700	930	1,160	1,210	1,820	2,110	2,400	[illegible]	[illegible]	4,300	670	950	1,050	1,430	1,680	1,930	2,540	3,110	[illegible]
C_k	3.05	2.0	1.7	1.30	1.1	0.8	0.65	0.61	0.45	3.4	2.6	2.22	1.71	1.3	1.1	0.9	0.703	0.553	3.81	2.63	2.34	1.87	1.46	1.19	0.97	0.72	0.56
C	0.025	0.0115	0.0065	0.01	0.006	0.0035	0.0055	0.003	0.0015	0.023	0.0115	0.007	0.012	[illegible]	[illegible]	0.006	0.0035	0.002	0.028	0.012	0.007	0.012	0.006	0.0035	0.006	[illegible]	0.002
E_o	8	11	14	12	15	18	14	18	20	15	28	32	28	34	41	32	36	44	39	52	60	50	59	66	55	70	75
V.G.	21	25	26	28	29	33	31	33	35	26	31	32	35	28	38	39	40	41	31	34	36	38	40	43	42	44	45

Resistance-coupled Amplifier Chart (Continued)

53*, 55, see Types 6N7 and 85, respectively, in this chart. 56, 57, see Type 76 and Types 6J7 and 6C6, respectively, in this chart. 75, 2A6, 6B6-G, 6SQ7

E_{bb}[1]	90									180									300								
R_L	0.1			0.25			0.5			0.1			0.25			0.5			0.1			0.25			0.5		
R_g[2]	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2
R_c	6,200	6,600	6,700	10,000	11,000	11,500	16,200	16,600	17,400	2,600	2,900	3,000	4,300	4,800	5,300	7,000	8,000	8,800	1,900	2,200	2,300	3,300	3,900	4,200	5,300	6,100	7,000
C_c	2.2	1.7	1.7	1.24	1.07	0.9	0.75	0.7	0.65	3.3	2.9	2.7	2.1	1.8	1.5	1.3	1.1	0.9	4	3.5	3	2.7	2	1.8	1.6	1.3	1.2
C	0.02	0.01	0.006	0.01	0.006	0.003	0.005	0.003	0.0015	0.025	0.015	0.007	0.015	0.007	0.004	0.007	0.004	0.002	0.03	0.015	0.007	0.015	0.007	0.004	0.007	0.004	0.002
E_o[3]	3	5	6	5	7	10	7	10	13	16	22	23	21	28	33	26	33	38	31	41	45	42	51	60	47	62	67
V.G.[4]	28[d]	29[a]	31[a]	34[b]	40[a]	40	39	44	48	29	36	37	43	50	53	52	57	58	31	39	42	48	53	56	58	60	63

76, 56

E_{bb}[1]	90									180									300								
R_L	0.05			0.1			0.25			0.05			0.1			0.25			0.05			0.1			0.25		
R_g[2]	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1
R_c	2,500	3,200	3,800	4,500	6,500	7,500	11,100	15,100	18,300	2,400	3,000	3,700	4,500	6,500	7,600	10,700	14,700	17,700	2,400	3,100	3,800	4,500	6,400	7,500	11,100	15,200	18,200
C_c	2	1.6	1.25	1.05	0.82	0.68	0.48	0.36	0.32	2.5	1.9	1.65	1.45	0.97	0.8	0.6	0.45	0.4	2.8	2.2	1.8	1.6	1.2	0.98	0.69	0.5	0.4
C	0.06	0.03	0.015	0.03	0.015	0.007	0.015	0.007	0.0035	0.06	0.035	0.015	0.035	0.015	0.008	0.015	0.007	0.0045	0.08	0.045	0.02	0.04	0.02	0.009	0.02	0.009	0.005
E_o[3]	16	21	23	19	23	25	21	24	28	36	48	55	45	55	57	49	59	64	65	80	95	74	95	104	82	96	108
V.G.[4]	7	7.7	8.1	8.1	8.9	9.3	9.4	9.7	9.8	7.7	8.2	9	9.3	9.5	9.8	9.7	10	10	8.3	8.9	9.4	9.5	10	10	10	10	10

79*

E_{bb}[1]	90									180									300								
R_L	0.1			0.25			0.5			0.1			0.25			0.5			0.1			0.25			0.5		
R_g[2]	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2	0.1	0.25	0.5	0.25	0.5	1	0.5	1	2
R_c‡	2,060	2,200	2,350	4,000	4,250	4,650	6,150	6,850	7,500	1,060	1,250	1,350	2,050	2,450	2,750	3,450	4,100	4,650	800	1,000	1,100	1,650	2,050	2,350	2,850	3,600	4,450
C	0.04	0.015	0.009	0.015	0.006	0.004	0.006	0.004	0.002	0.04	0.02	0.009	0.02	0.01	0.005	0.009	0.0035	0.002	0.025	0.01	0.006	0.01	0.0065	0.003	0.0055	0.003	0.0015
E_o[3]	5.8	8.4	9.5	7.1	9.7	12	8.8	12	15	21	27	31	26	34	40	30	39	44	40	57	60	56	66	77	61	75	82
V.G.[4]	22[d]	29[a]	29	31[a]	33	35	34	38	40	27	31	34	37	41	42	42	44	45	29	34	33	39	42	43	44	46	46

85, 55

E_{bb}[1]	90									180									300								
R_L	0.05			0.1			0.25			0.05			0.1			0.25			0.05			0.1			0.25		
R_g[2]	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1	0.05	0.1	0.25	0.1	0.25	0.5	0.25	0.5	1
R_c	3,800	4,600	5,400	6,620	9,000	10,300	15,100	20,500	24,400	3,200	4,100	5,000	6,200	8,700	10,000	14,500	20,000	24,000	3,200	4,100	5,100	5,900	8,300	9,600	14,300	19,400	23,600
C_c	1.4	1.1	0.86	0.7	0.55	0.5	0.31	0.25	0.2	1.8	1.6	1.2	0.9	0.7	0.57	0.43	0.29	0.21	1.9	1.5	1.2	0.8	0.54	0.43	0.3	0.22	0.2
C	0.06	0.03	0.015	0.04	0.015	0.007	0.015	0.007	0.004	0.06	0.045	0.02	0.04	0.015	0.008	0.015	0.008	0.004	0.03	0.045	0.015	0.03	0.015	0.006	0.01	0.006	0.003
E_o[3]	16	19	23	17	22	25	18	23	26	33	44	49	37	47	50	40	48	53	50	74	85	64	82	88	71	84	94
V.G.[4]	4.5	4.9	5.1	5.1	5.4	5.5	5.3	5.5	5.6	4.9	5.2	5.3	5.3	5.5	5.5	5.6	5.7	5.7	5.2	5.5	5.6	5.5	5.7	5.8	5.7	5.7	5.8

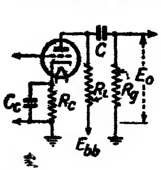
Taken from RCA Handbook Series HB-3, Dec 20, 1938, by courtesy of RCA Manufacturing Company, Inc.

* The cathodes of the two units have a common terminal. † The cathodes of the two units have separate terminals. ‡ Values are for phase-inverter service. See notes under Resistance-coupled Phase-inverter diagram.

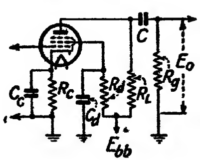
[1] Voltage at plate equals plate-supply voltage minus voltage drop in R_L and R_c. For other supply voltages differing by as much as 50 per cent from those listed, the values of resistors, condensers, and gain are approximately correct. The value of voltage output, however, for any of these other supply voltages equals the listed voltage output multiplied by the new plate-supply voltage divided by the plate-supply voltage corresponding to the listed voltage output. [2] For following stage (see circuit diagrams).

[3] Voltage across R_g at grid-current point. [4] Voltage gain at 5 volts (r.m.s.) output unless index letter indicates otherwise. [a] At 2 volts (r.m.s.) output. [b] At 3 volts (r.m.s.) output. [c] At 4 volts (r.m.s.) output. [d] At 2.2 volts (r.m.s.) output.

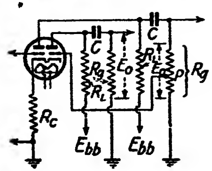
RESISTANCE-COUPLED TRIODE AMPLIFIER
Using single triode or one unit of twin-triode type with separate cathode terminals



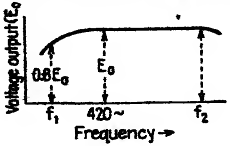
RESISTANCE-COUPLED PENTODE AMPLIFIER



RESISTANCE-COUPLED PHASE INVERTER
Using twin-triode type with one cathode terminal



FREQUENCY CHARACTERISTIC OF SINGLE-STAGE RESISTANCE-COUPLED TRIODE AMPLIFIER

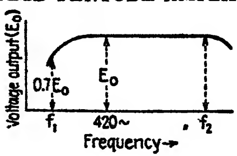


A. Condensers C and C_c have been chosen to give output voltages equal to 0.8 E_o for f_1 of 100 cycles. For any other value of f_1, multiply values of C and C_c by $\frac{100}{f_1}$.

In the case of condenser C_c, the values shown are for an amplifier with d-c heater excitation. When a.c. is used, depending on the character of the associated circuits, the gain, and the value of f_1, it may be necessary to increase the value of C_c to minimize hum disturbances. It may also be desirable to have a d-c potential difference of approximately 10 volts between heater and cathode.

B. f_2 = frequency at which high-frequency response begins to fall off.
C. The voltage output of f_1 for n like stages equals $(0.8\ E_o)^n$.
D. Decoupling filters are not necessary for two stages or less.
E. For an amplifier of typical construction, the value of f_2 is well above the audio-frequency range for any value of R_L.
F. Always use highest permissible value of R_g.
G. A variation of ±10 per cent in values of resistors and condensers has only a slight effect on performance.

FREQUENCY CHARACTERISTIC OF SINGLE-STAGE RESISTANCE-COUPLED PENTODE AMPLIFIER

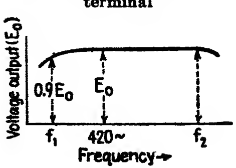


A. Condensers C, C_c, and C_d have been chosen to give output voltages equal to $0.7E_o$ for f_1 of 100 cycles. For any other value of f_1, multiply values of C, C_c, and C_d by $\frac{100}{f_1}$. In the case of condenser C_c, the values shown are for an amplifier with d-c heater excitation. When a.c. is used, depending on the character of the associated circuits, the gain, and the value of f_1, it may be necessary to increase the value of C_c to minimize hum disturbances. It may also be desirable to have a d-c potential difference of approximately 10 volts between heater and cathode.

B. f_2 = frequency at which high-frequency response begins to fall off.
C. The voltage output at f_1 for n like stages equals $(0.7\ E_o)^n$.
D. Decoupling filters are not necessary for two stages or less.
E. For an amplifier of typical construction, approximate values of f_2 for different values of R_L are: 0.1meg., 20,000 cps; 0.25 meg., 10,000 cps; 0.5 meg., 5,000 cps.
F. Always use highest permissible value of R_g.
G. A variation of ±10 per cent in values of resistors and condensers has only slight effect on performance.

RESISTANCE-COUPLED PHASE INVERTER

Using twin-triode type with one cathode terminal



The signal input is supplied to the grid of the left-hand triode unit. The grid of the right-hand unit obtains its signal from a tap (P) on the grid resistor (R_g) in the output circuit of the left-hand triode unit. The tap (P) is chosen so as to make the voltage output of the right-hand unit equal to that of the left-hand unit. Its location is determined from the voltage gain values given in the Chart. For example, if the value of voltage gain is 20 (from the Chart), (P) is chosen so as to supply $\frac{1}{20}$ of the voltage across (R_c) to the grid of the right-hand triode.

For phase-inverter service, the cathode resistor (R_c) should not be by-passed by a condenser. Omission of the condenser in this service assists in balancing the output voltages. The value of (R_c) is specified on the basis that both units are operating simultaneously at the same values of plate load and plate voltage.

REGULATIONS OF THE NATIONAL BOARD OF FIRE UNDERWRITERS FOR RADIO INSTALLATIONS

Article 810—Radio Equipment

8101. Scope. This article shall apply to radio receiving equipment and to amateur radio transmitting equipment, but shall not apply to equipment and antennas used for coupling carrier current to power line conductors.

It is recommended that the authority enforcing this code be freely consulted as to the specific methods to be followed in any case of doubt relative to installation of antenna and counterpoise conductors and that the National Electrical Safety Code, Part 5, be followed

8102. Application of Other Articles. Wiring from the source of power to and between devices connected to the interior wiring system shall comply with Chapters 1 to 4, inclusive, except as modified by sections 6403, 6404 and 6405. Wiring for radio-frequency and audio-frequency equipment and loud speakers shall comply with Article 640.

Antenna Systems—General

8111. Material. Antenna, counter-poise, and lead-in conductors shall be of hard drawn copper, bronze, copper-clad steel or other high-strength, corrosion-resistant material. Soft-drawn or medium-drawn copper may be used for lead-in conductors where the maximum span between points of support is less than 35 feet.

8112. Supports. Outdoor antenna and counter-poise and lead-in conductors shall be securely supported. They shall not be attached to poles or similar structures carrying electric light or power wires or trolley wires of more than 250 volts. Insulators supporting the antenna or counter-poise conductors shall have sufficient mechanical strength to safely support the conductors. Lead-in conductors shall be securely attached to the antenna.

8113. Avoidance of Contacts with Conductors of Other Systems. Outdoor antenna, counterpoise and lead-in conductors from an antenna to a building shall not cross over electric light or power circuits and shall be kept away from all such circuits so

as to avoid the possibility of accidental contact. Where proximity to electric light and power service conductors of less than 250 volts cannot be avoided, the installation shall be such as to provide a clearance of at least two feet. It is recommended that antenna and counterpoise conductors be so installed as not to cross under electric light or power conductors.

8114. Splices. Splices and joints in antenna and counter-poise span shall be made with approved splicing devices or by such other means as will not appreciably weaken the conductors.

Soldering may ordinarily be expected to weaken the conductor. Therefore, when soldering is employed it should be independent of the mechanical support.

8115. Indoor Antenna. There are no requirements for indoor antennas except that they shall have the same clearance from the conductors of electric light and power circuits and signaling circuits as is required for lead-in conductors.

ANTENNA SYSTEMS—RECEIVING STATION

8121. Size of Antenna and Counter-poise. Outdoor antenna and counter-poise conductors for receiving stations shall be of a size not less than given in the following table:

	Minimum size of conductors when maximum open span length is		
	Less than 35 feet	35 feet to 150 feet	Over 150 feet
Hard-drawn copper..................	19	14	12
Copper-clad steel, bronze or other high strength material..................	20	17	14

For very long span lengths larger conductors will be required depending on the length of the span and the ice and wind loading.

8122. Size of Lead-in. Lead-in conductors from outside antenna, and counter-poise for receiving stations, shall, for various maximum open span lengths, be of such size as to have a tensile strength at least as great as that of the conductors for

antenna as specified in section 8121. When the lead-in consists of two or more conductors which are twisted together or are enclosed in the same covering or are concentric, the conductor size shall, for various maximum open-span lengths, be such that the tensile strength of the combination will be at least as great as that of the conductors for antenna as specified in section 8121.

8123. On Buildings. Lead-in conductors attached to buildings shall be so installed that they cannot swing closer than 2 feet to the conductors of circuits of 250-volts or less, or 10 feet to the conductors of circuits of more than 250 volts; except in the case of circuits not exceeding 150 volts, if all conductors involved are supported so as to insure a permanent separation the clearance may be reduced but shall not be less than 4 inches. The clearance between lead-in conductors and any conductor forming a part of a lightning rod system shall not be less than six feet.

8124. Electric Supply Circuits Used in Lieu of Antenna. If an electric supply circuit is used in lieu of an antenna, the device by which the radio receiving set is connected to the supply circuit shall be specially approved for the purpose.

Protectors

8141. Lightning Arresters—Receiving Stations. Each conductor of a lead-in from an outdoor antenna shall be provided with a lightning-arrester approved for the purpose, except where the lead-in conductors from antenna to entrance to building are protected by a continuous metallic shield which is permanently and effectively grounded. Lightning arresters shall be located outside the building, or inside the building between the point of entrance of the lead-in and the radio set or transformers, and as near as practicable to the entrance of the conductors to the building. The lightning arrester shall not be located near combustible material nor in a hazardous location.

Grounding Conductors—General

8151. Material. The grounding conductor shall, unless otherwise specified, be of copper, copper-clad steel, bronze, or other corrosion-resistant material.

8152. Insulation. The grounding conductors may be uninsulated.

8153. Supports. The grounding conductors shall be securely fastened in place and may be directly attached to the surface wired over without the use of insulating supports.

8154. Mechanical Protection. The grounding conductor shall be protected where exposed to mechanical injury.

8155. Run in Straight Line. The grounding conductor shall be run in as straight a line as practicable from the equipment to the grounding electrode.

8156. Ground Electrode. The grounding conductor shall be connected to a grounding electrode as specified in sections 2581 and 2582 of Article 250.

Grounding Conductors—Receiving Stations

8161. Inside or Outside Building. The grounding conductor may be run either inside or outside the building.

8162. Size of Protective Ground. The protective grounding conductor for receiving stations shall be not smaller than No. 14 copper or No. 17 copper-clad steel or bronze, provided that where wholly inside the building it shall not be smaller than No. 18.

8163. Common Ground. A single grounding conductor may be used for both protective and operating purposes.

If a single conductor is so used, the ground terminal of the equipment should be connected to the ground terminal of the protective device.

Interior Installation—General

8181. Clearance from Other Conductors. Except as provided in Article 640, all conductors inside the building shall be separated at least 4 inches from the conductor of any other light or signal circuit unless separated therefrom by conduit or some firmly fixed non-conductor such as porcelain tubes or flexible tubing.

HELPFUL BOOKS AND MAGAZINES

"A. C. Radio Guide," by Kenneth A. Hathaway, American Technical Society.

"Making a Living in Radio," by Zeh Bouck, McGraw-Hill Book Company, Inc.

"Radio Construction and Repairing," by James A. Moyer and John F. Wostrel, McGraw-Hill Book Company, Inc.

"Principles of Radio Engineering,"[1] by R. S. Glasgow, McGraw-Hill Book Company, Inc.
"Electron Tubes," by John H. Morecroft, John Wiley & Sons, Inc.
"Radio Engineering,"[1] by F. E. Terman, McGraw-Hill Book Company, Inc.
"Modern Radio Servicing," by A. A. Ghirardi, Radio and Technical Publishing Co.
"D. C. Voltage Distribution," by John F. Rider, John F. Rider.
"Alternating Currents in Radio Receivers," by John F. Rider, John F. Rider.
"Resonance and Alignment," by John F. Rider, John F. Rider.
"Automatic Volume Control," by John F. Rider, John F. Rider.
"Servicing Superheterodynes," by John F. Rider, John F. Rider.
"Aligning Philco Receivers," by John F. Rider, John F. Rider.
"Cathode-ray Tube at Work," by John F. Rider, John F. Rider.
"Radio Manual," by John F. Rider, John F. Rider.
"Frequency Modulation," by John F. Rider, John F. Rider.
"Communication Engineering,"[1] by W. L. Everitt, McGraw-Hill Book Company, Inc.

Service
Radio Craft
Communications
Radio Today
Electronics
Successful Servicing
Sylvania News
Aerovox Research Worker

[1] These are college textbooks that require a knowledge of calculus for complete understanding. However, there is much very instructive material in the nonmathematical portion, which any student can read with profit.

INDEX

G

H

I

K

L

Acc. No. 3169

Duration of Loan

Students/Spl/C
Text Books — 3 days
Technical Books — 7 days
General Books — 14 days

Teachers—
One month

FROM THE DATE OF ISSUE